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**Kang et al.**

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(54) **INTEGRATED CIRCUIT DEVICES**

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**Related U.S. Patent Documents**

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**H01L 27/088** (2006.01)

(Continued)

(52) **U.S. Cl.**

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(58) **Field of Classification Search**

CPC . H01L 29/0673; H01L 29/1054; H01L 29/20;  
H01L 29/2003; H01L 29/205; H01L 29/7841; H01L 29/66795; H01L 29/785  
See application file for complete search history.

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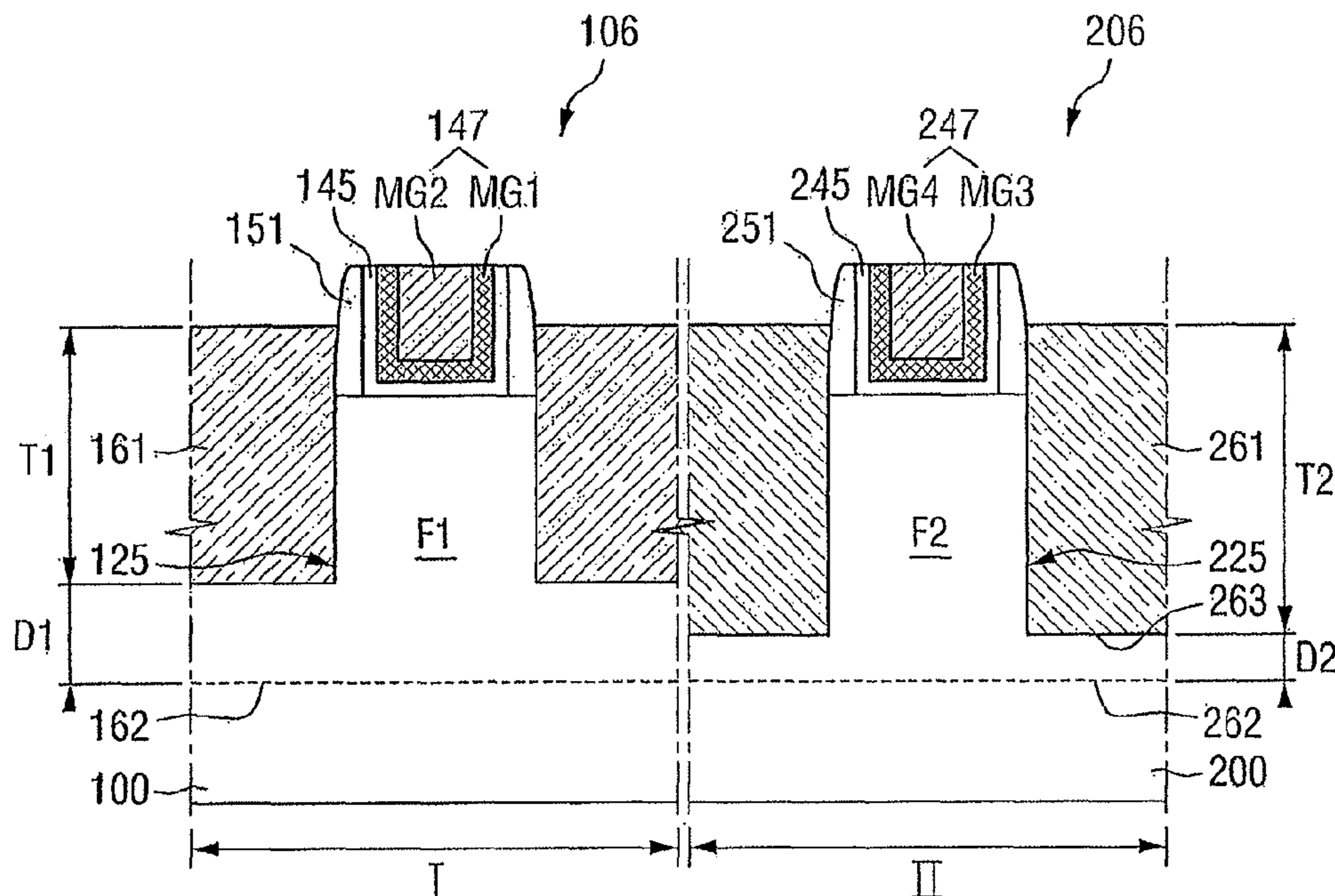
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(57) **ABSTRACT**

An integrated circuit device includes a first transistor having a first channel between a first source/drain, and a second transistor having a second channel between a second source/drain. The first transistor operates based on a first amount of current and the second transistor operates based on a second amount of current different from the first amount of current. The first and second channels have fixed channel widths. The fixed channel widths may be based on fins or nanowires included in the first and second transistors.

**39 Claims, 29 Drawing Sheets**



# US RE49,988 E

**Related U.S. Application Data**

the reissue of Pat. No. 9,673,099, which is a division of application No. 14/162,052, filed on Jan. 23, 2014, now Pat. No. 9,324,850.

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*H01L 29/66* (2006.01)  
*H01L 29/775* (2006.01)  
*H01L 29/78* (2006.01)  
*H01L 21/84* (2006.01)  
*H01L 27/12* (2006.01)  
*H01L 29/06* (2006.01)  
*H01L 29/423* (2006.01)  
*H01L 29/786* (2006.01)

(52) **U.S. Cl.**

CPC .... *H01L 21/823431* (2013.01); *H01L 21/845* (2013.01); *H01L 27/0886* (2013.01); *H01L 27/1211* (2013.01); *H01L 29/0673* (2013.01); *H01L 29/42392* (2013.01); *H01L 29/66439* (2013.01); *H01L 29/66795* (2013.01); *H01L 29/7848* (2013.01); *H01L 29/78696* (2013.01)

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FIG. 1

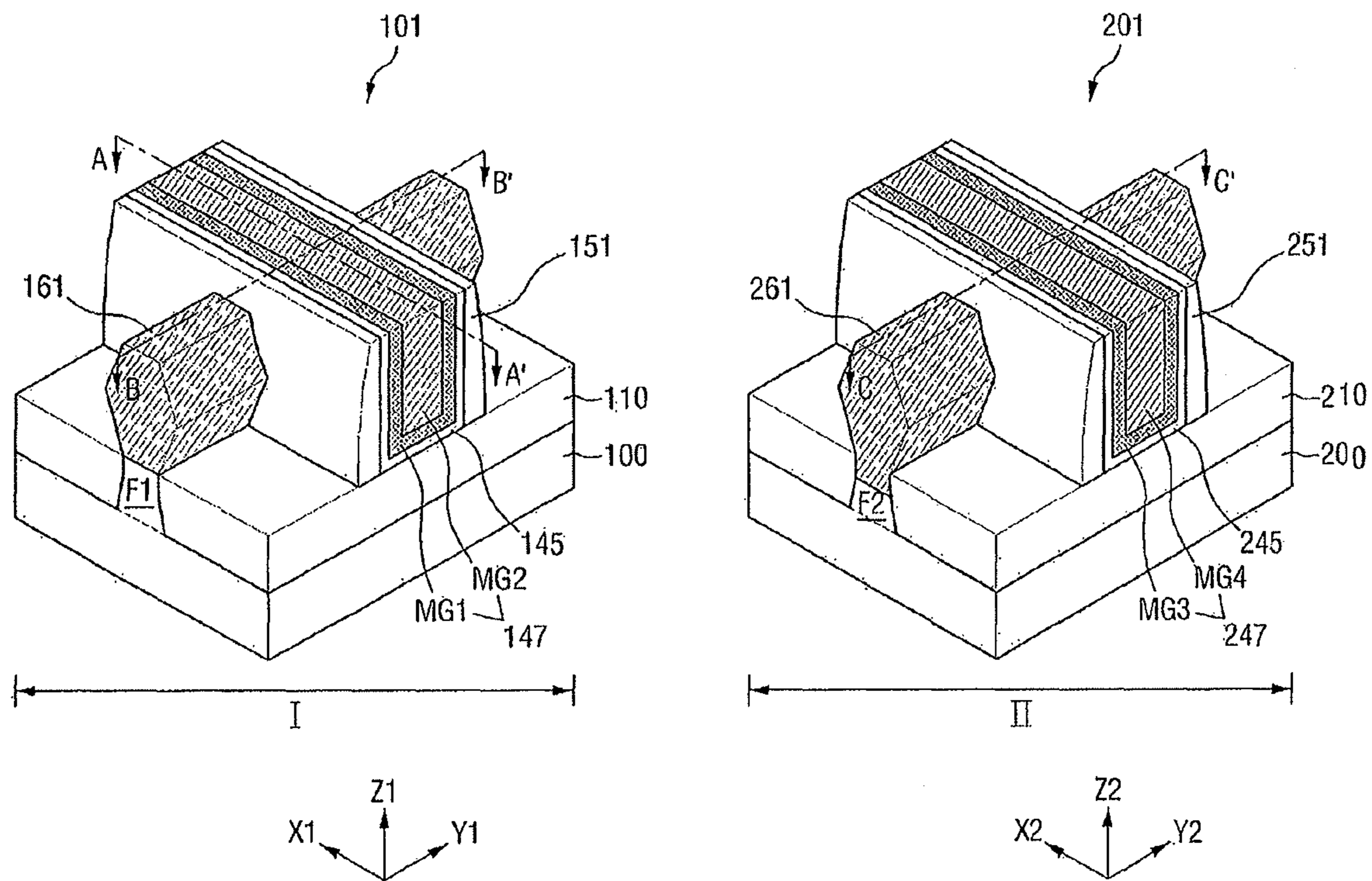


FIG. 2

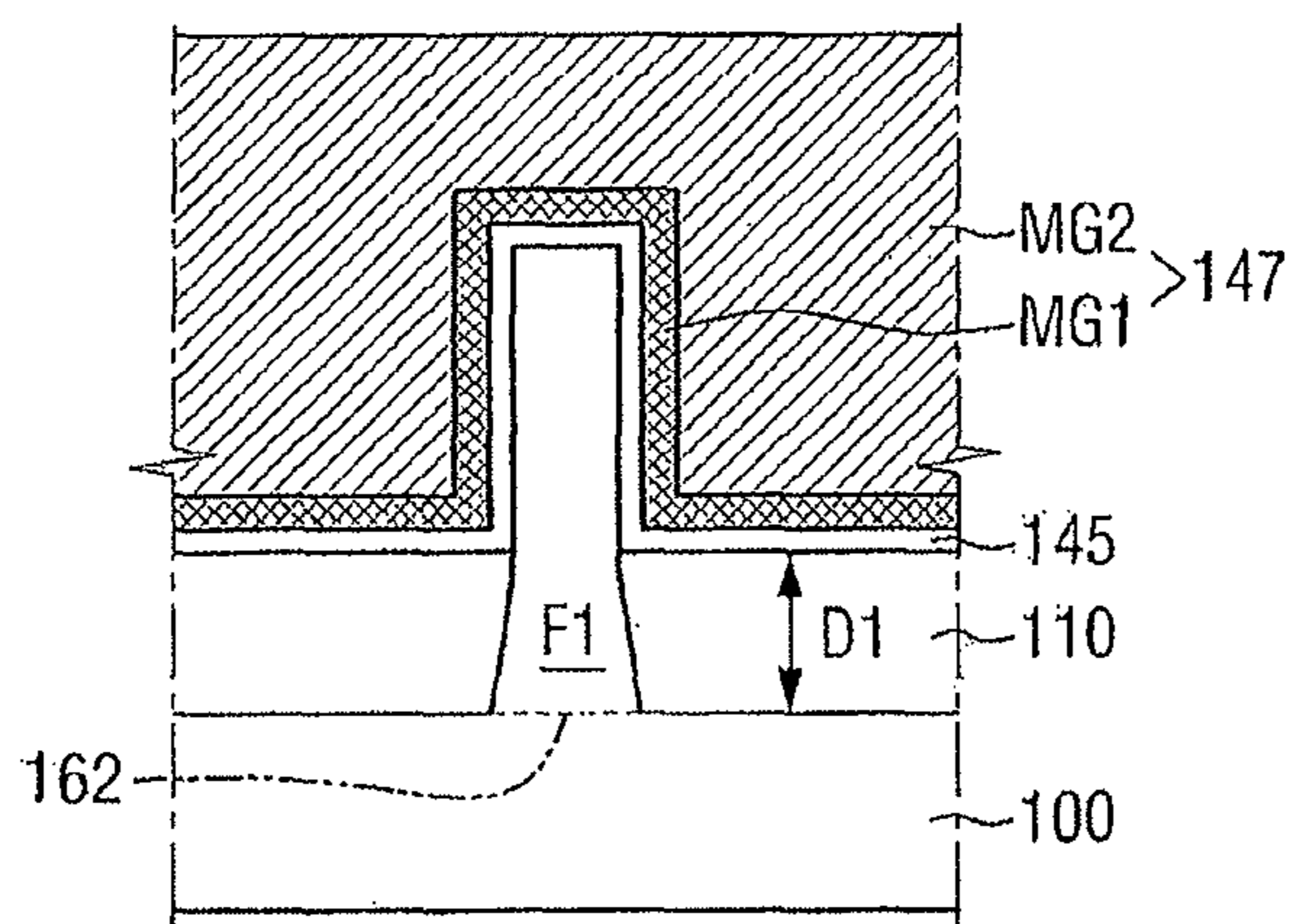


FIG. 3

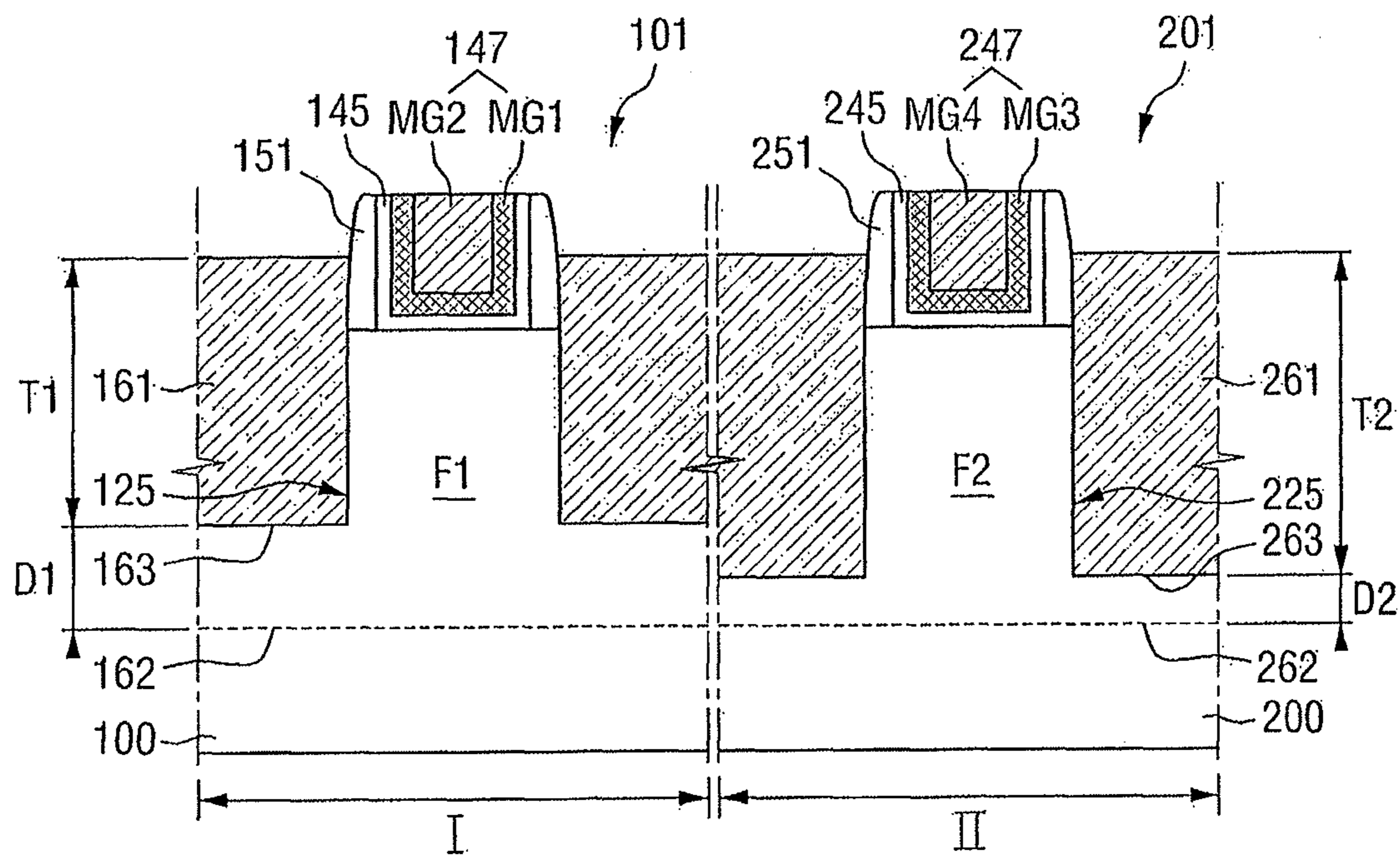


FIG. 4

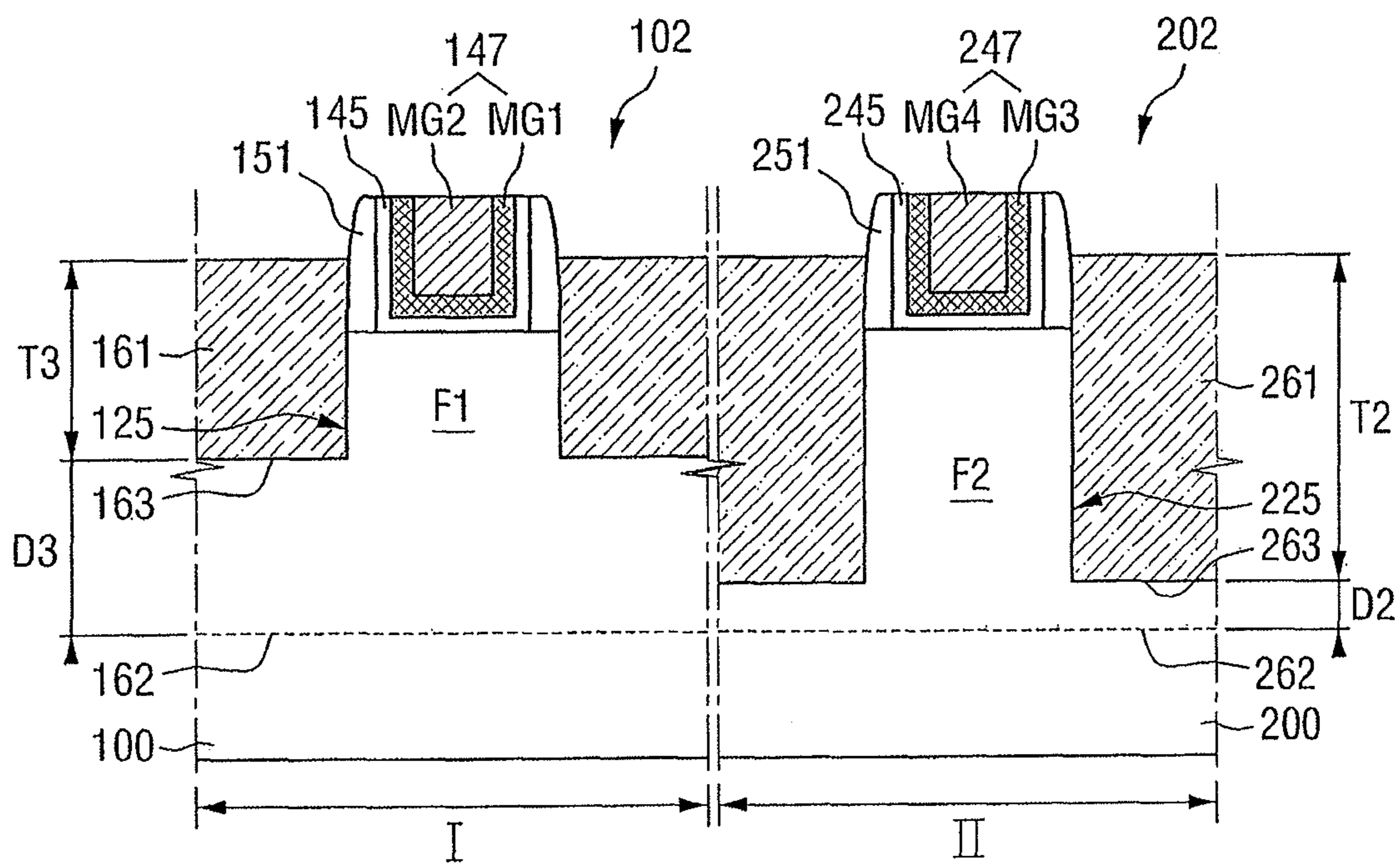


FIG. 5

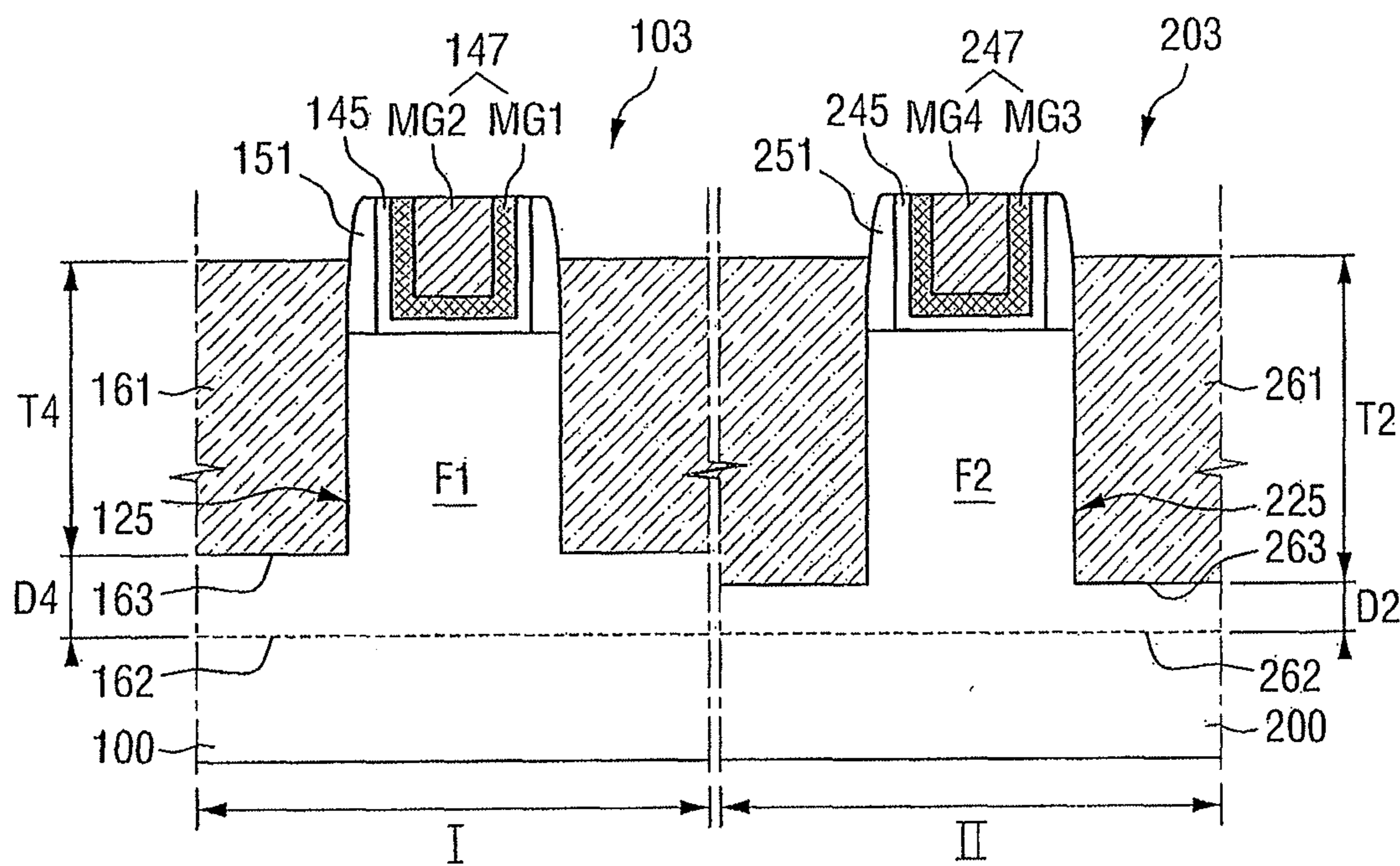


FIG. 6

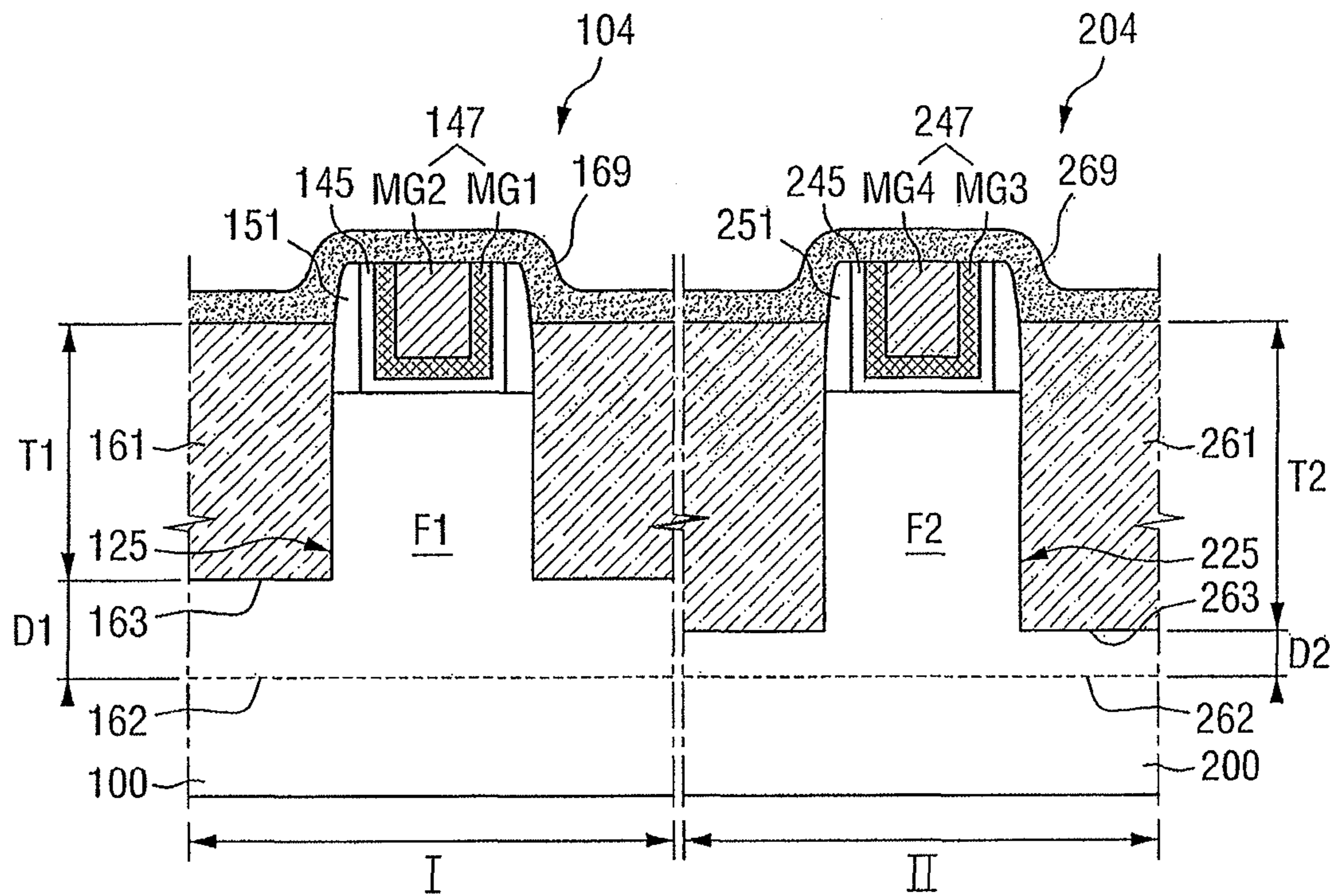


FIG. 7

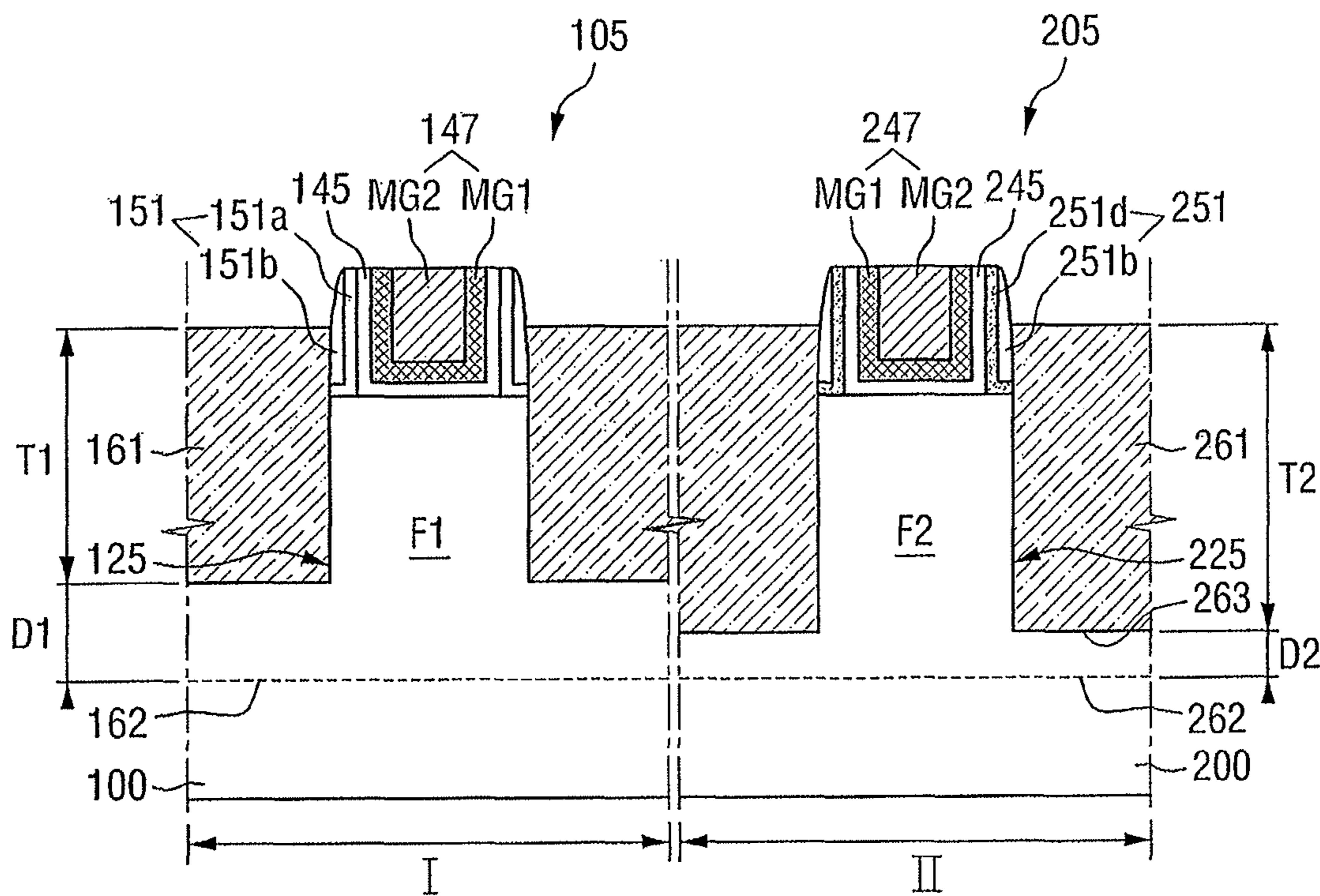


FIG. 8

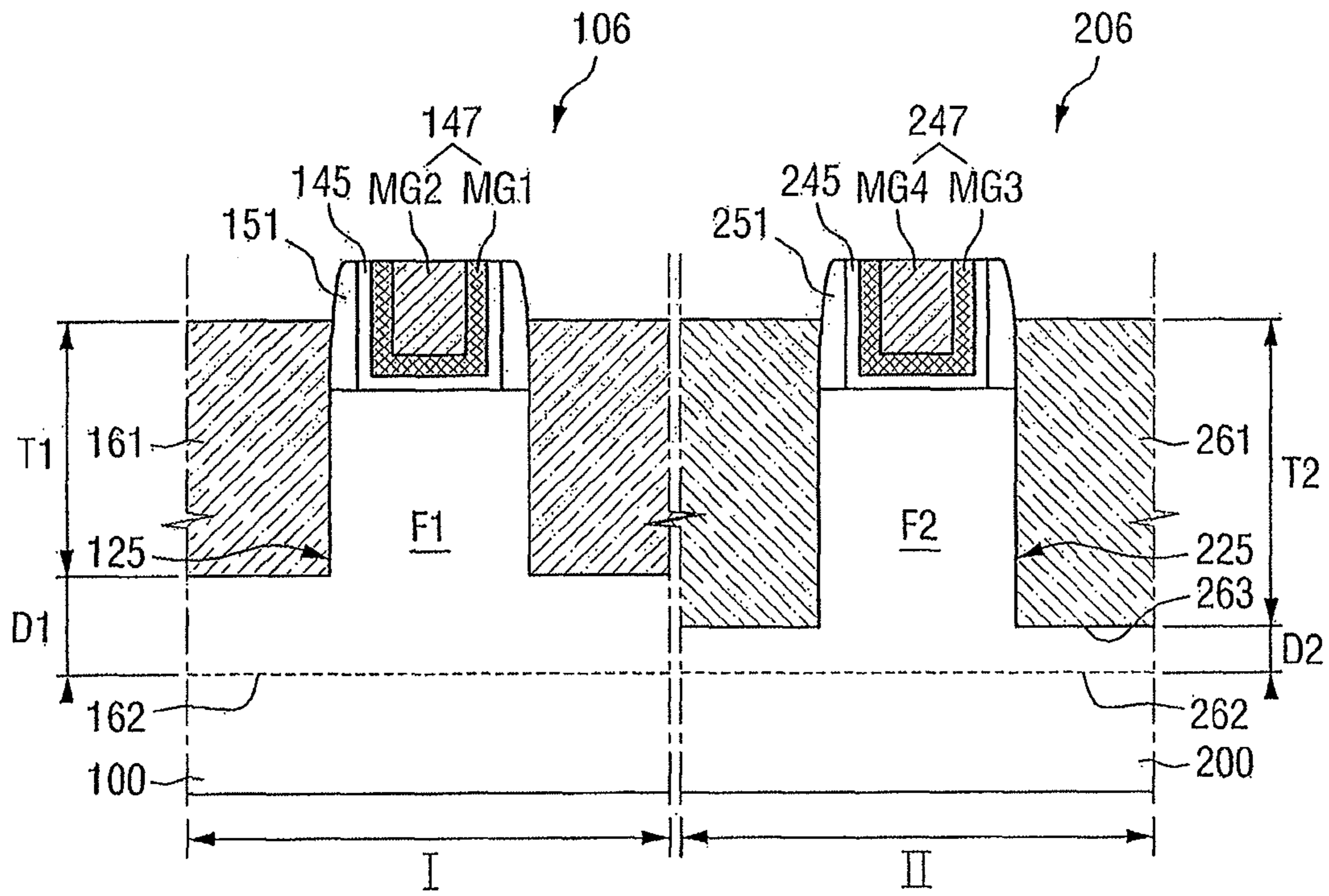


FIG. 9A

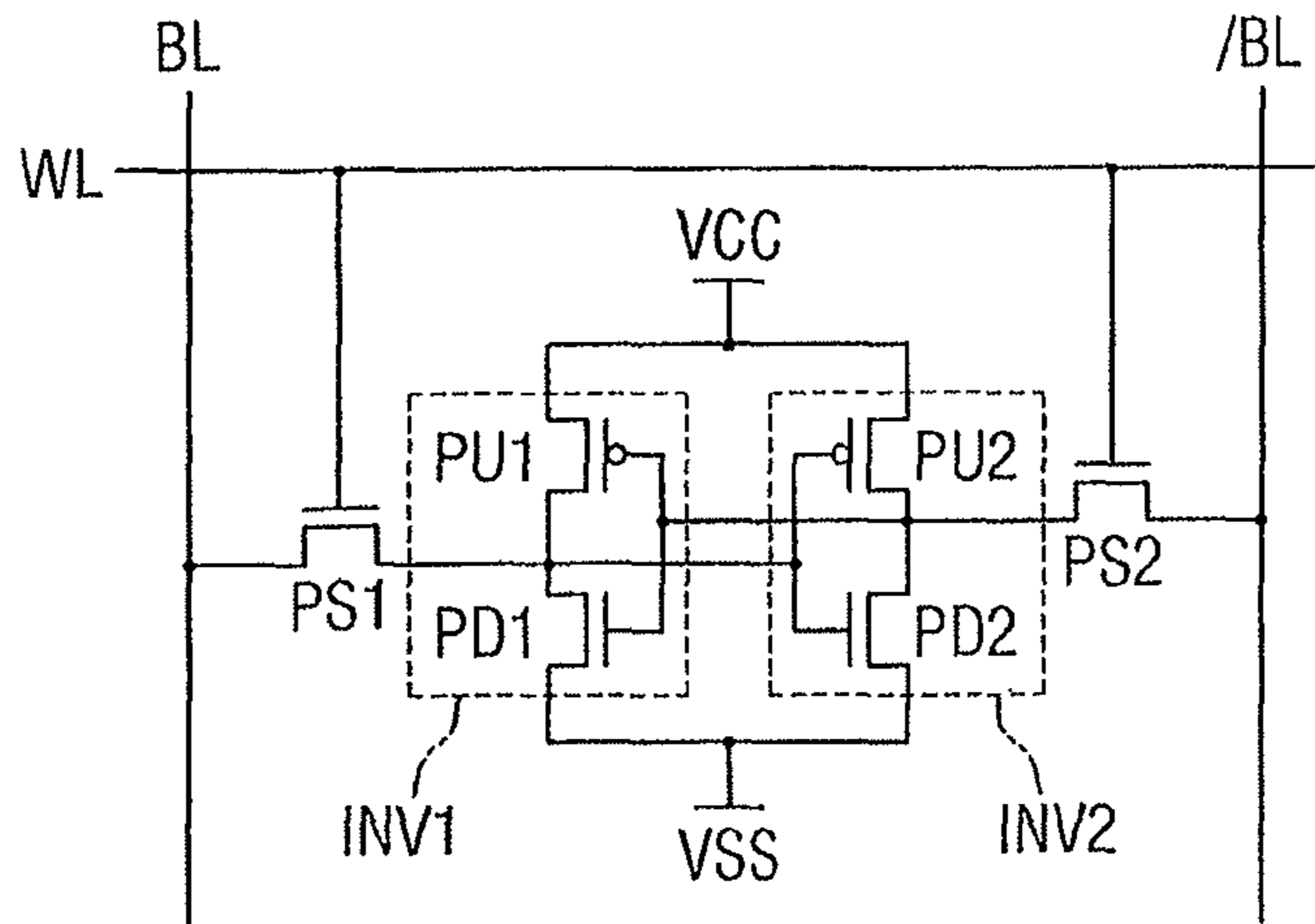




FIG. 9B

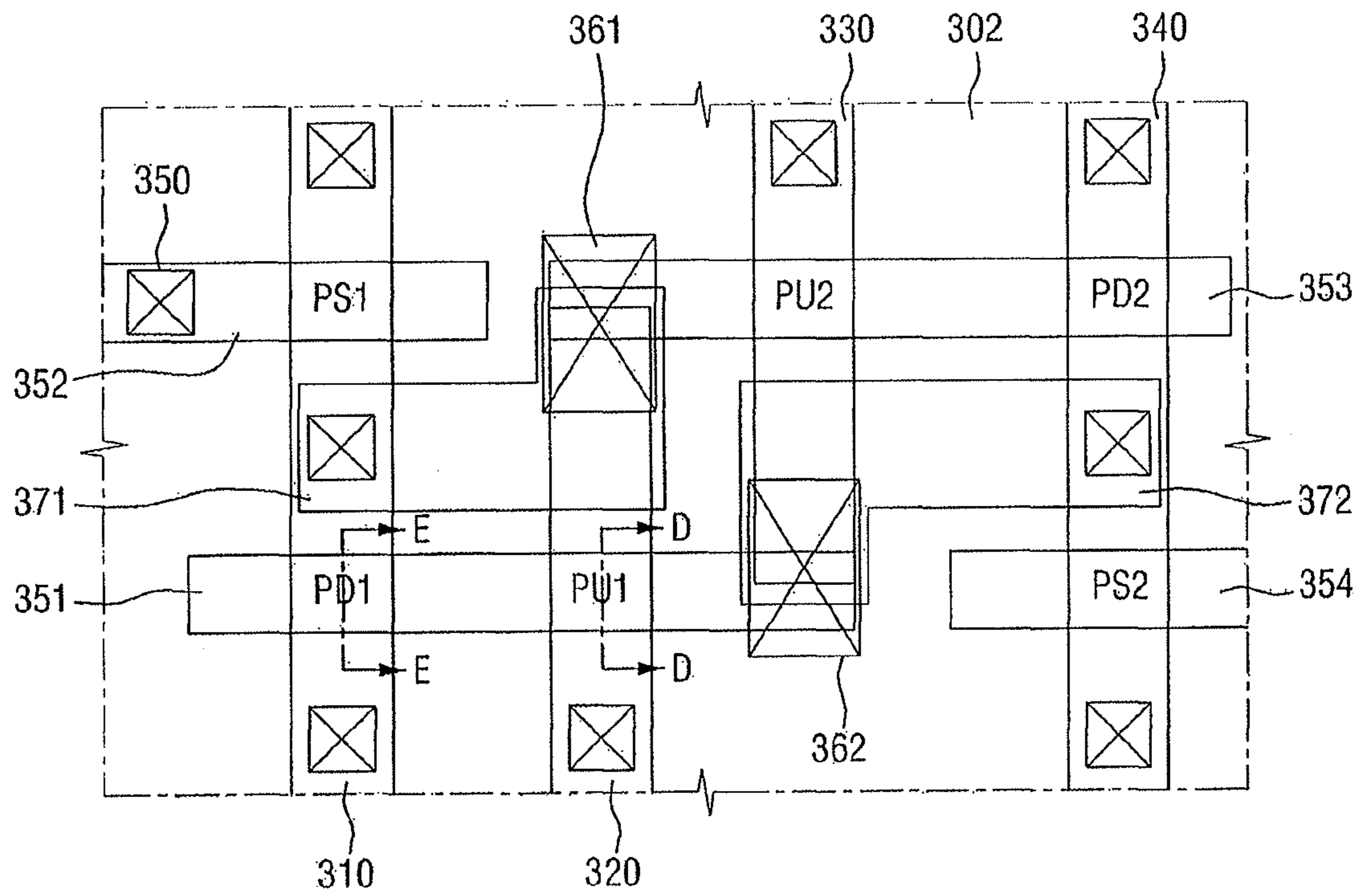
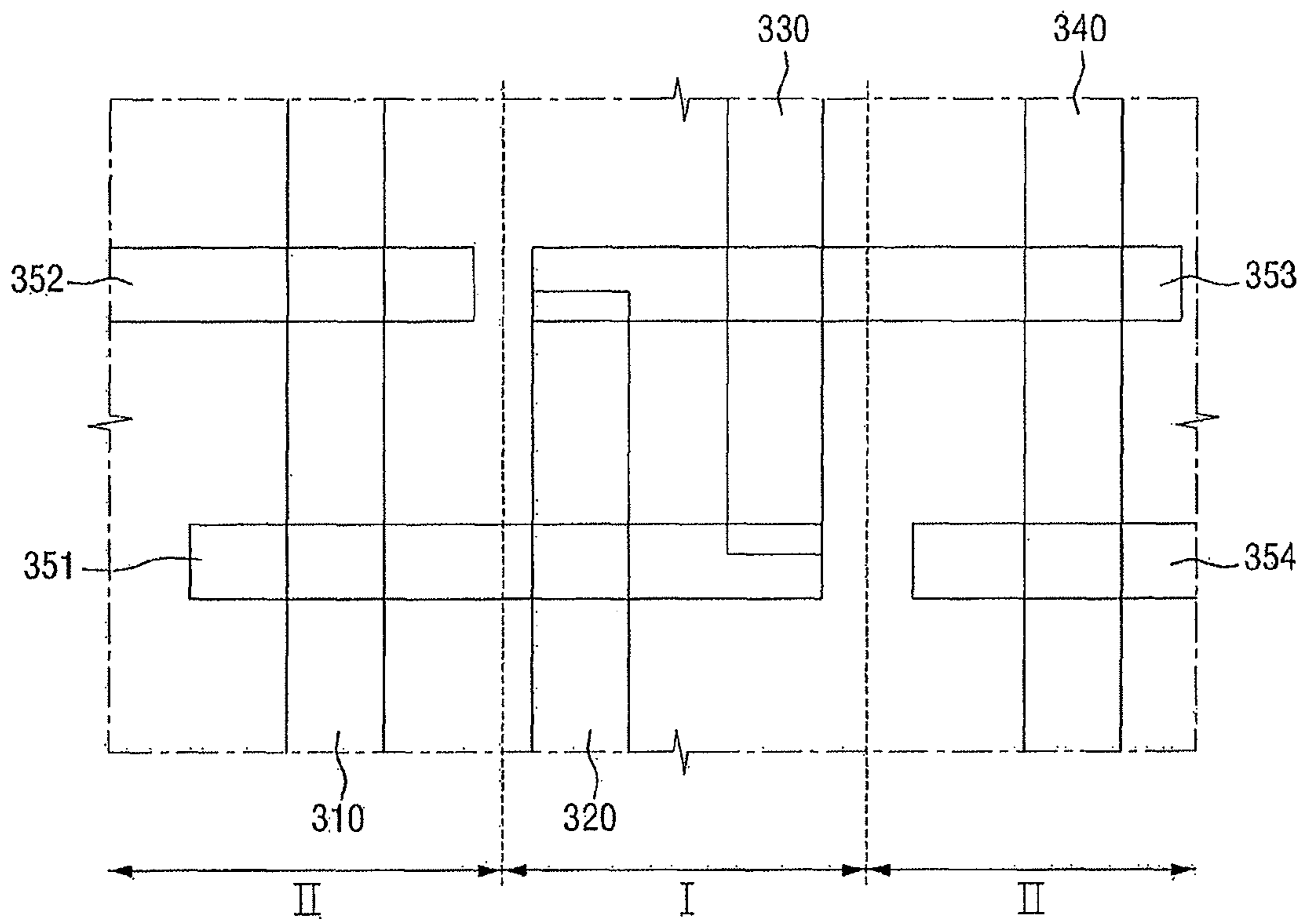
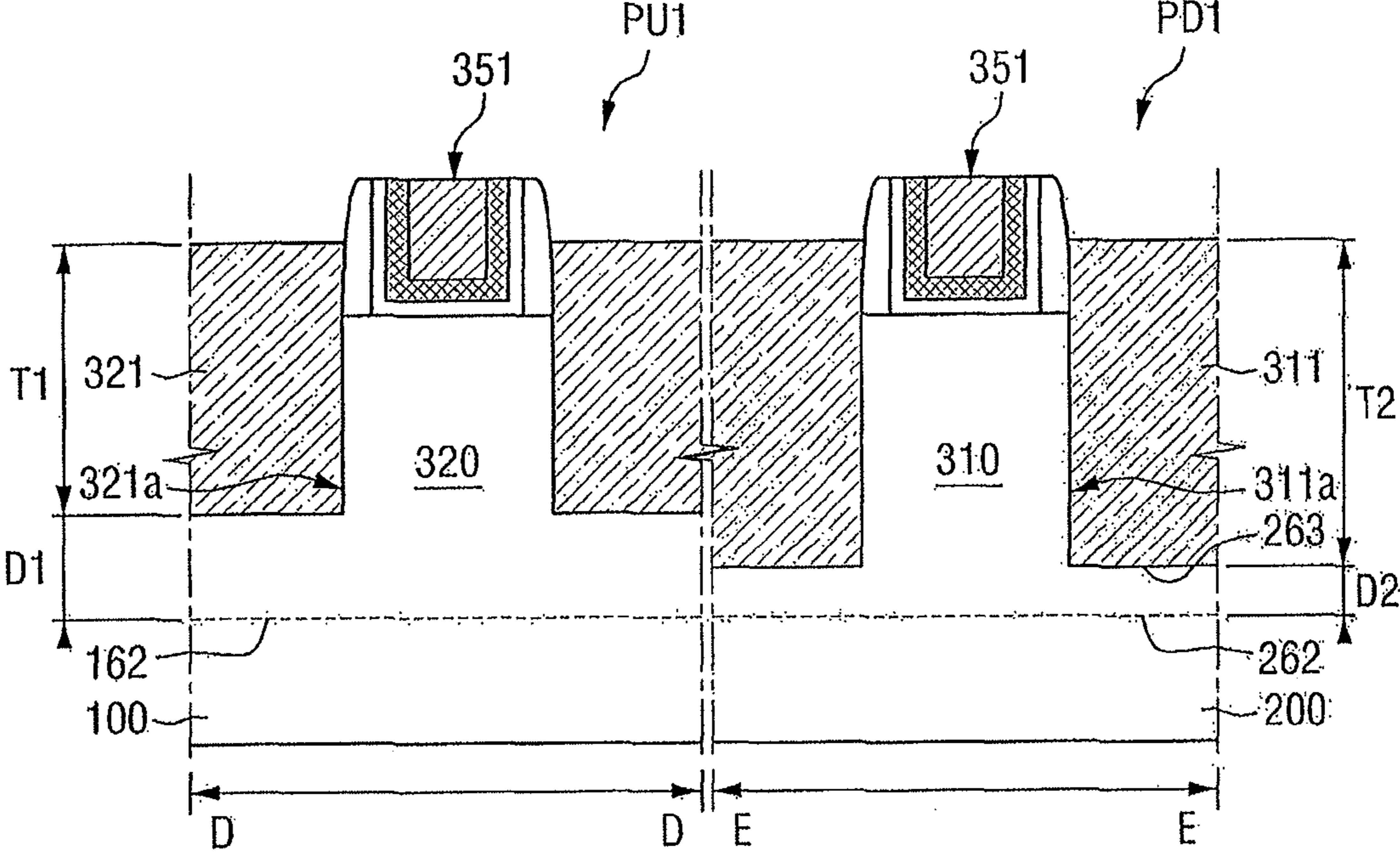


FIG. 9C



**FIG. 9D**



**FIG. 10A**

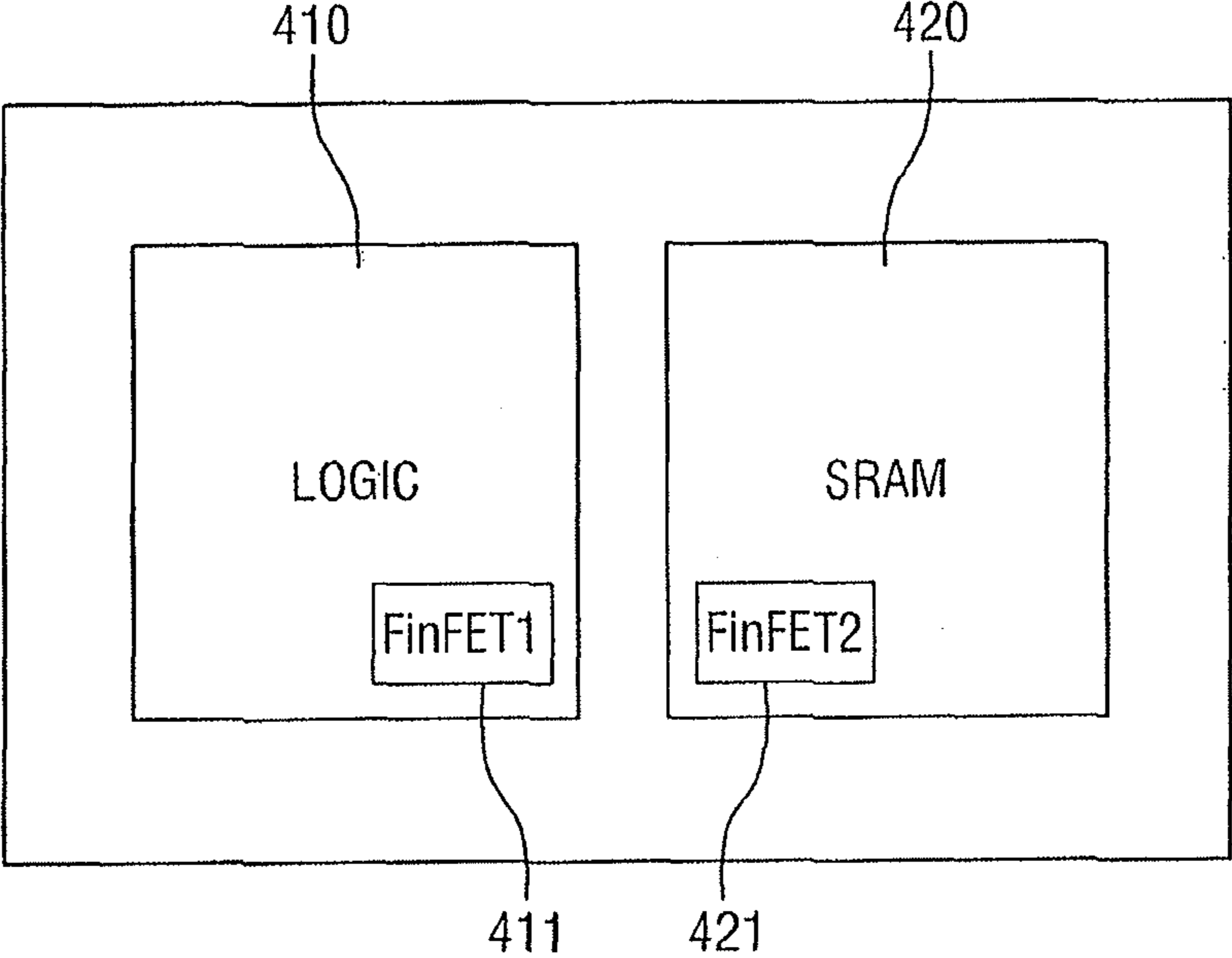


FIG. 10B

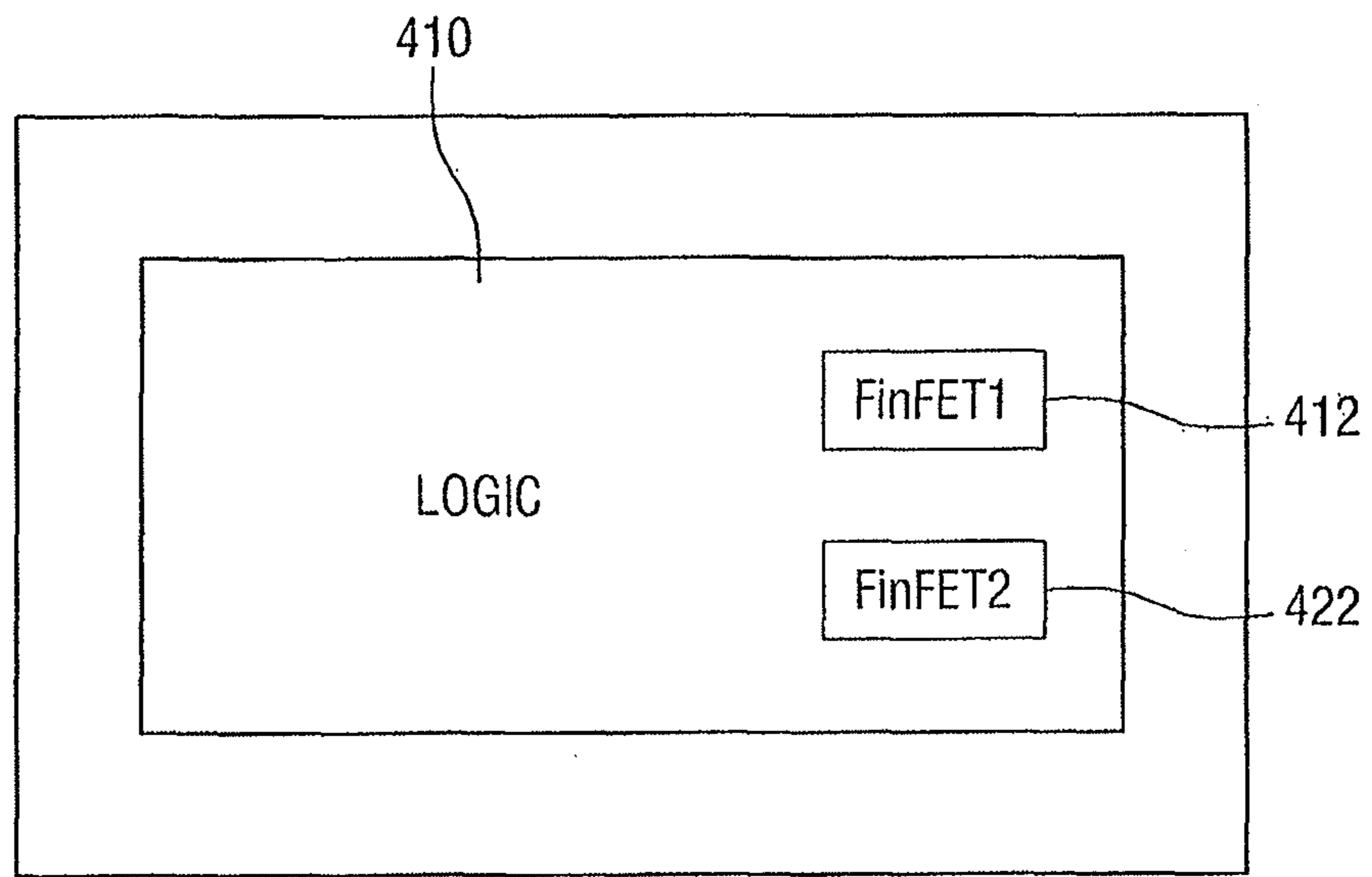


FIG. 10C

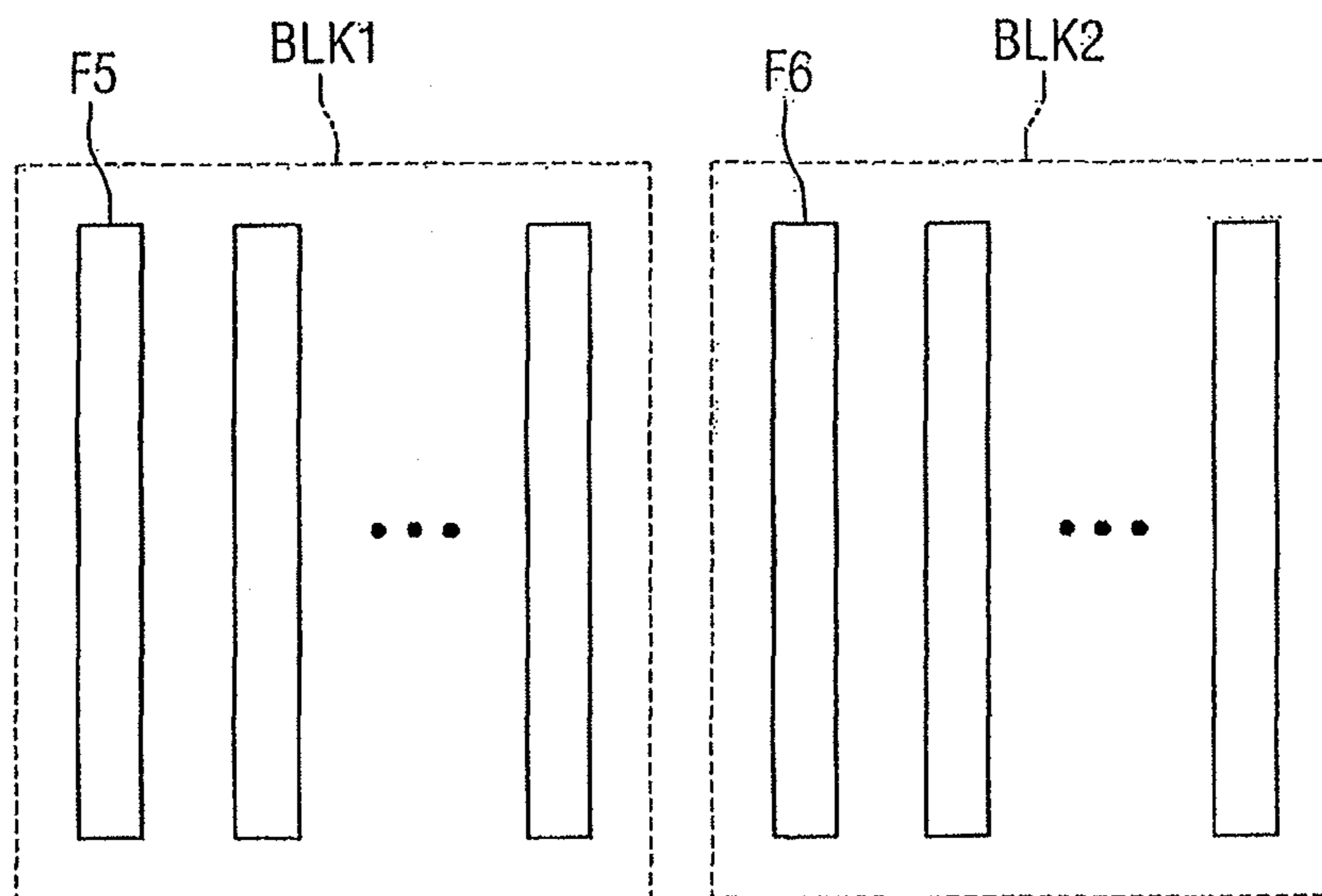


FIG. 11A

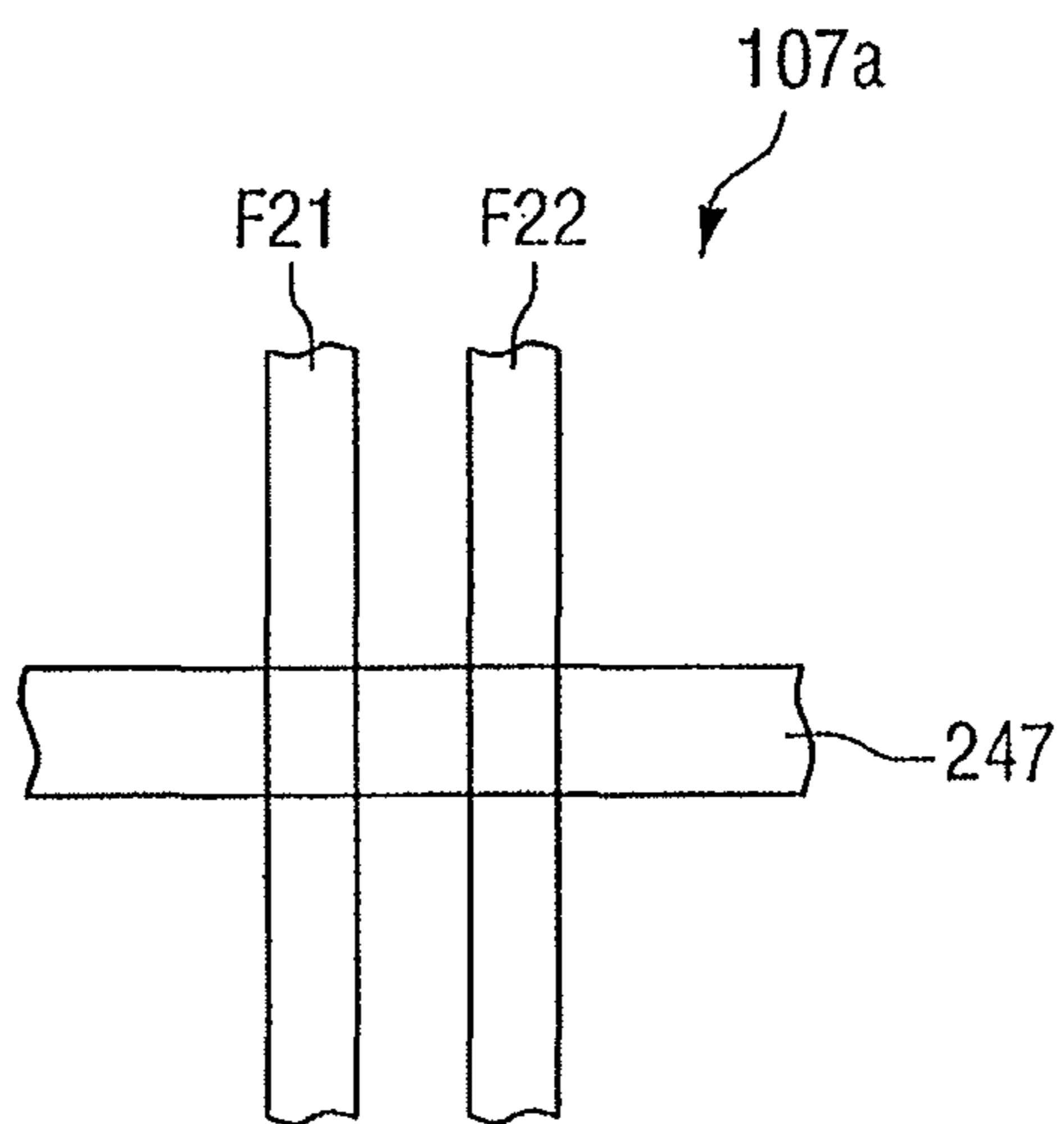
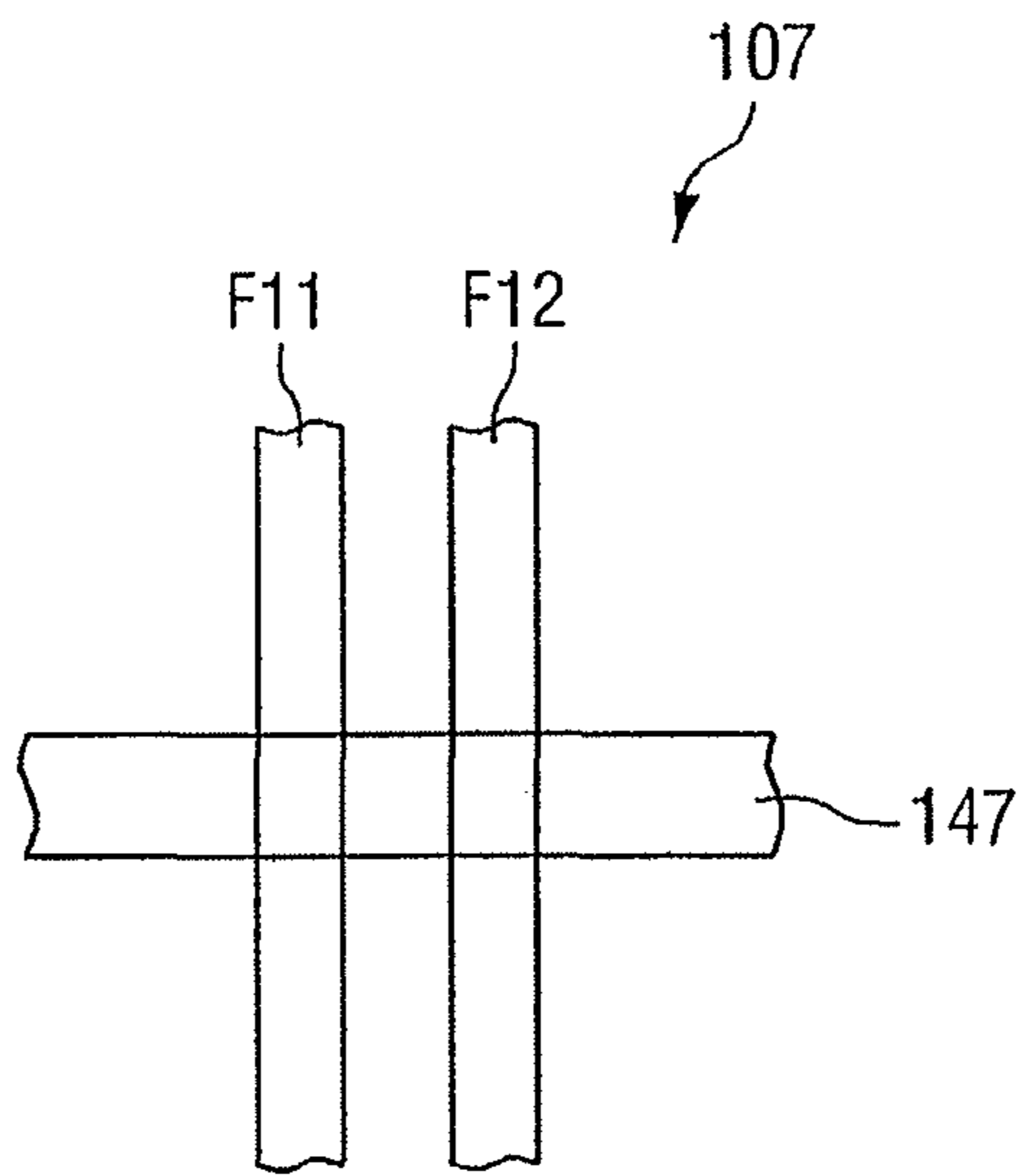


FIG. 11B

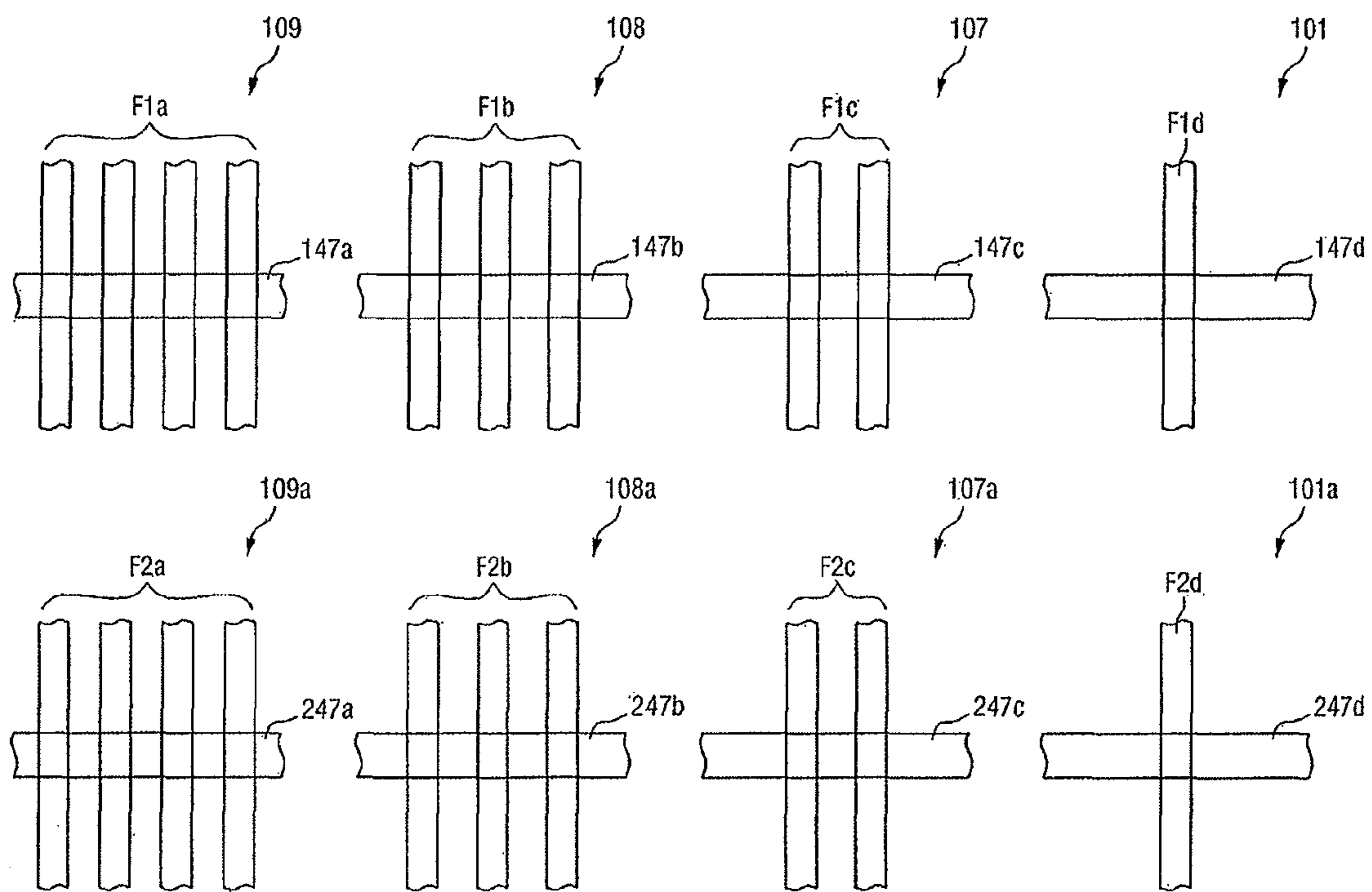


FIG. 12

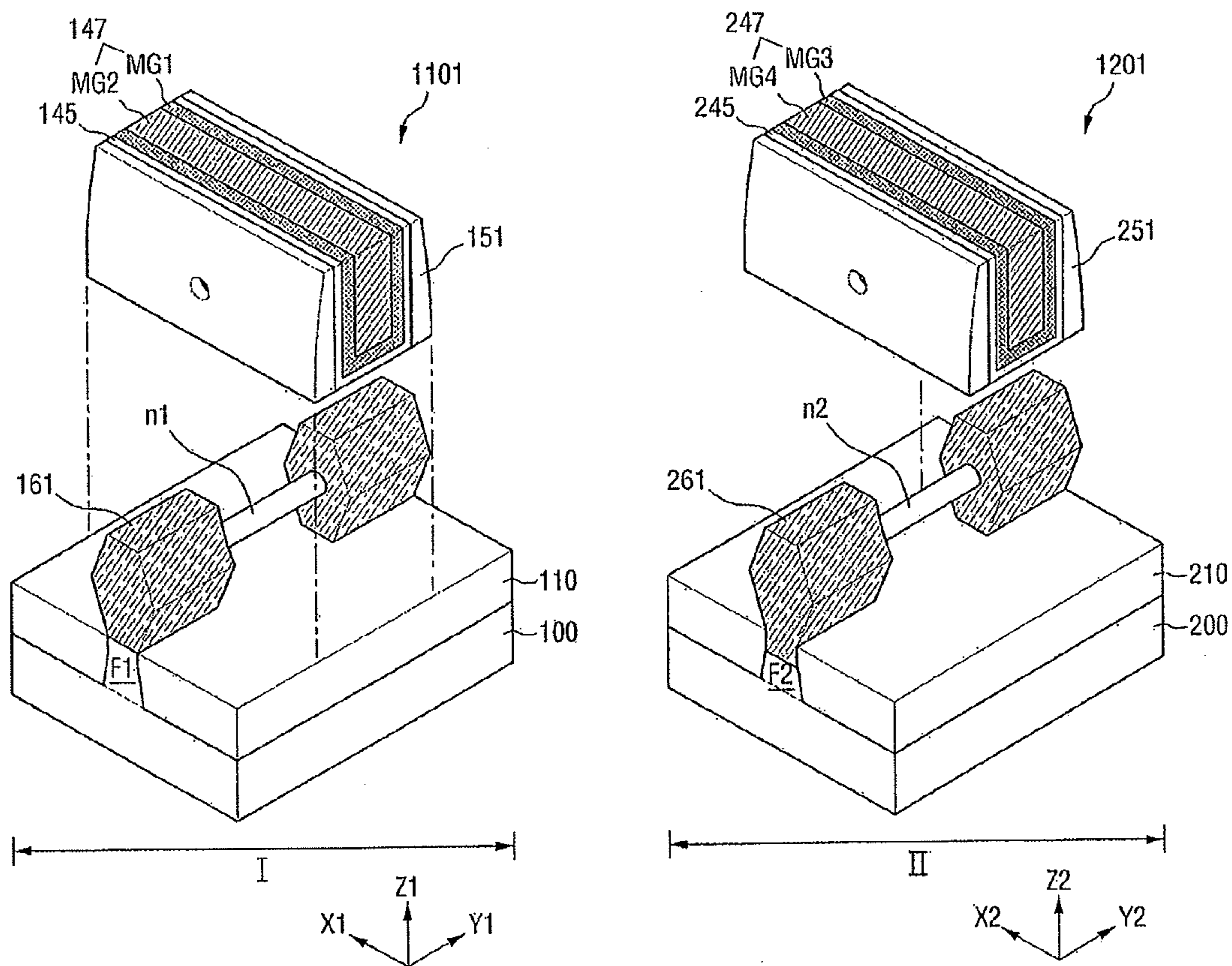


FIG. 13A

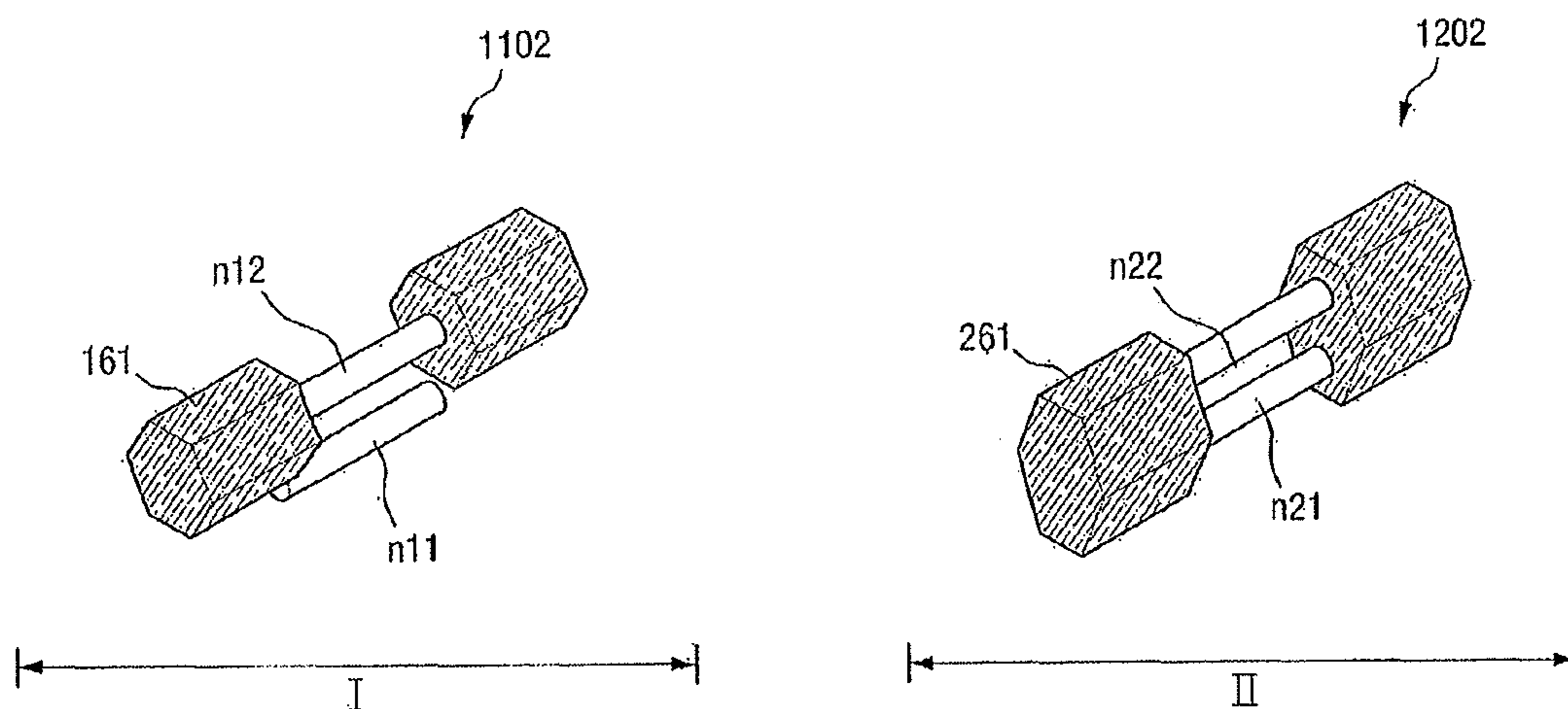


FIG. 13B

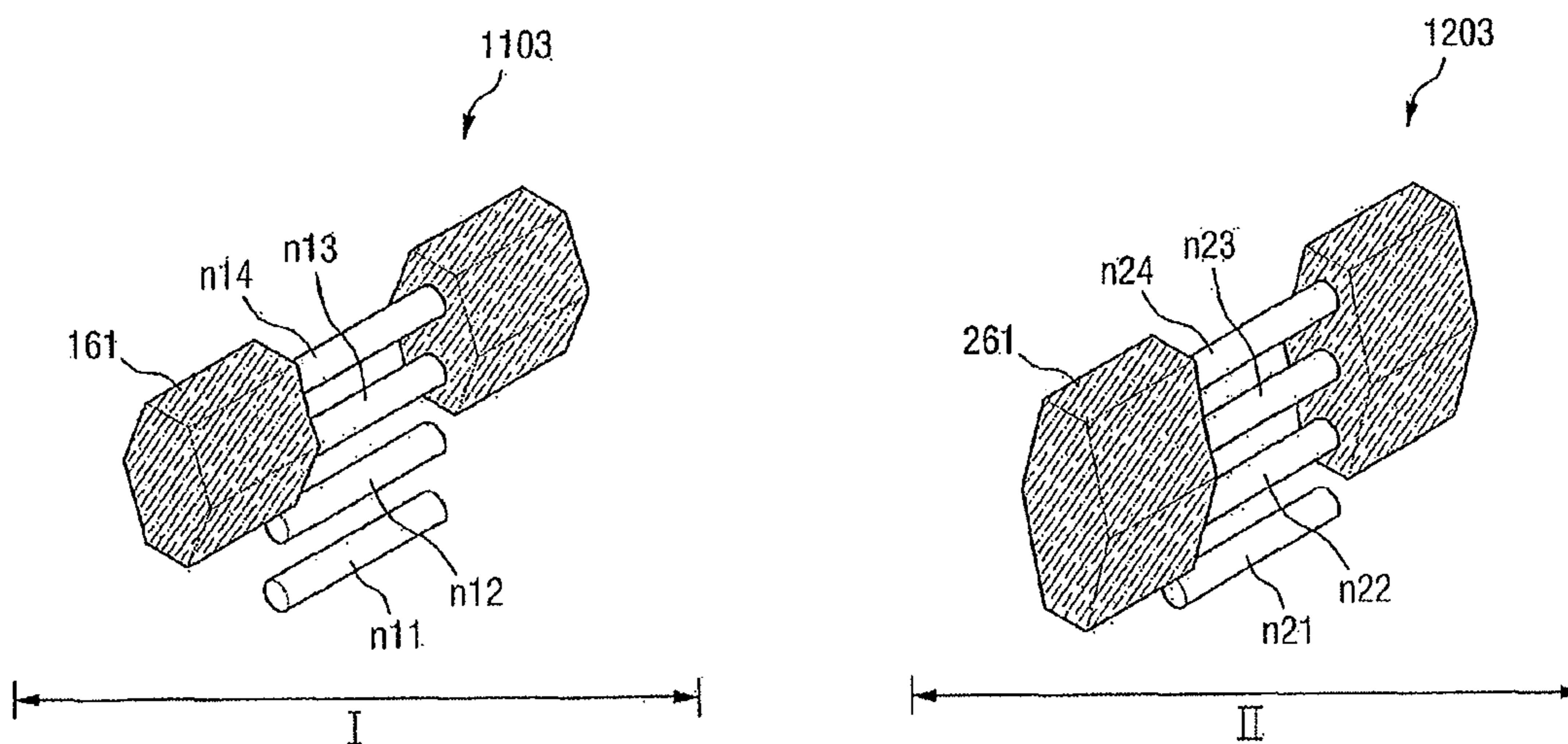




FIG. 14

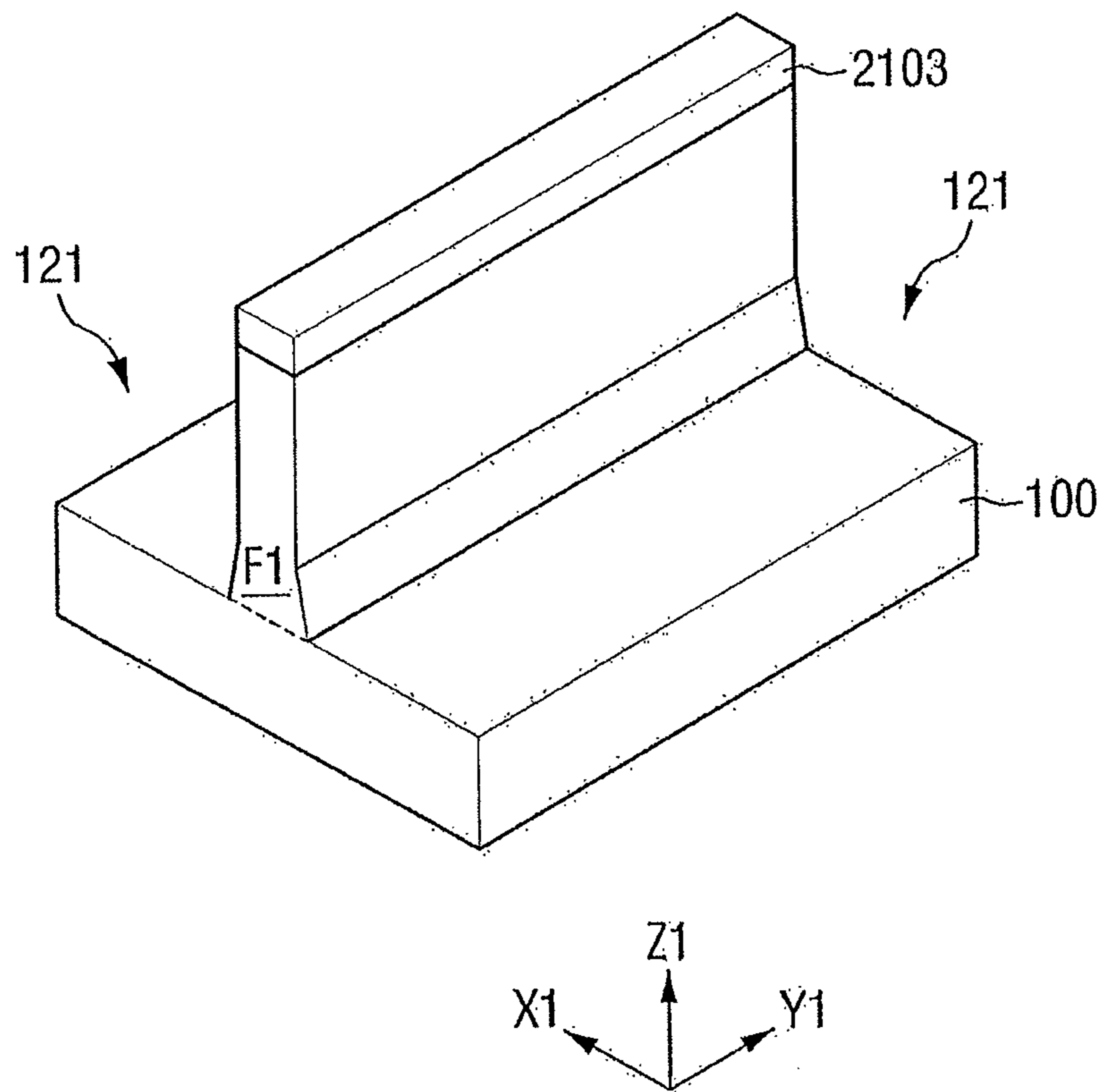


FIG. 15

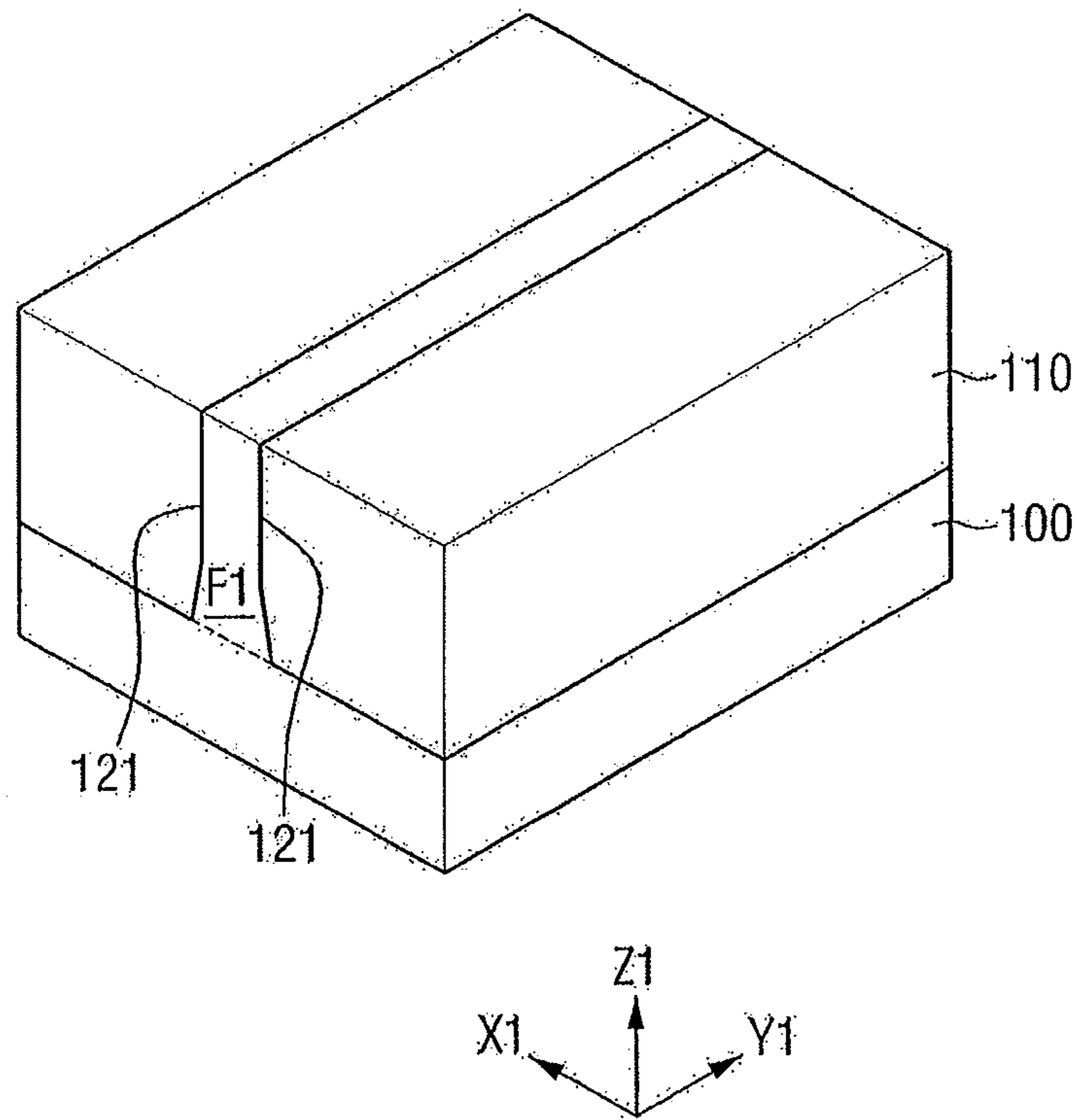


FIG. 16

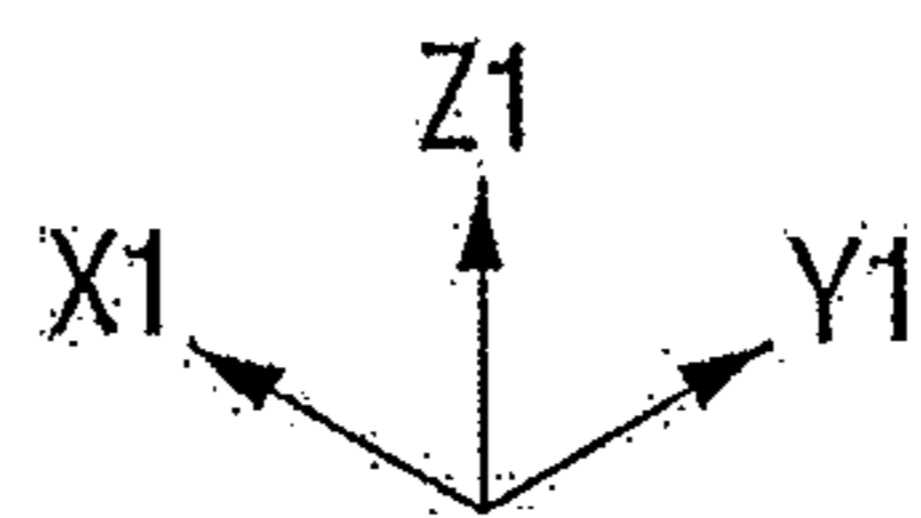
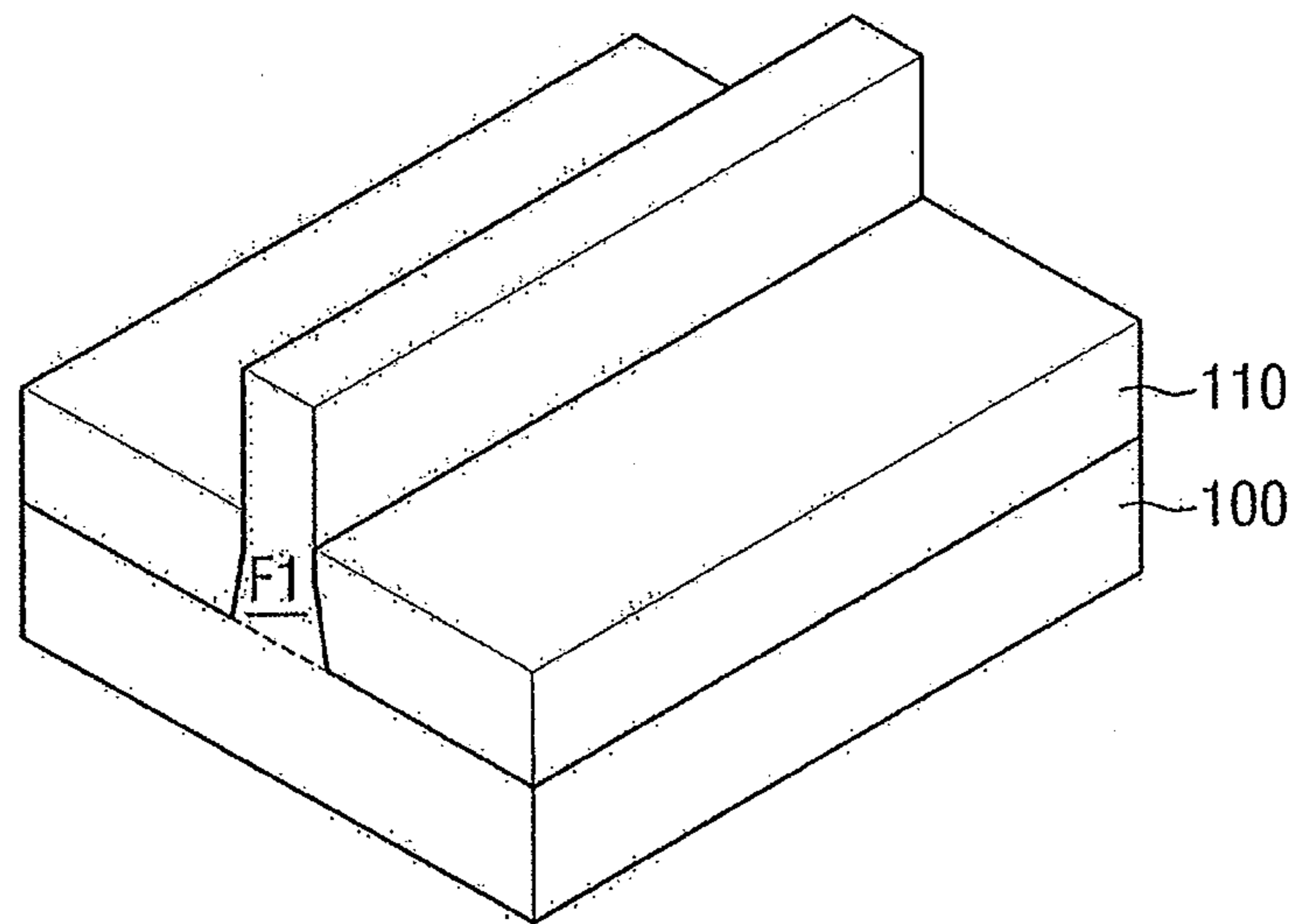


FIG. 17

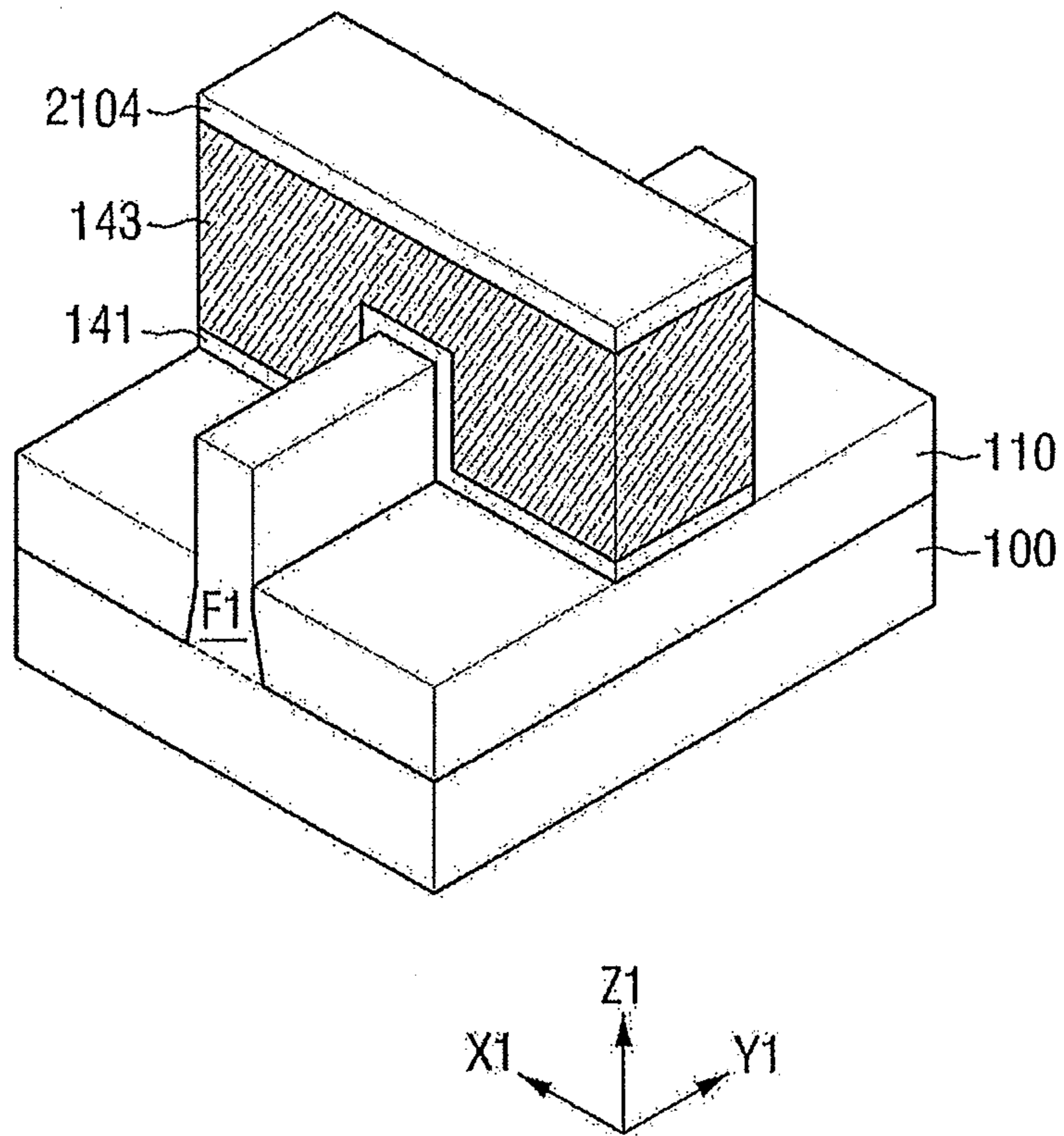


FIG. 18

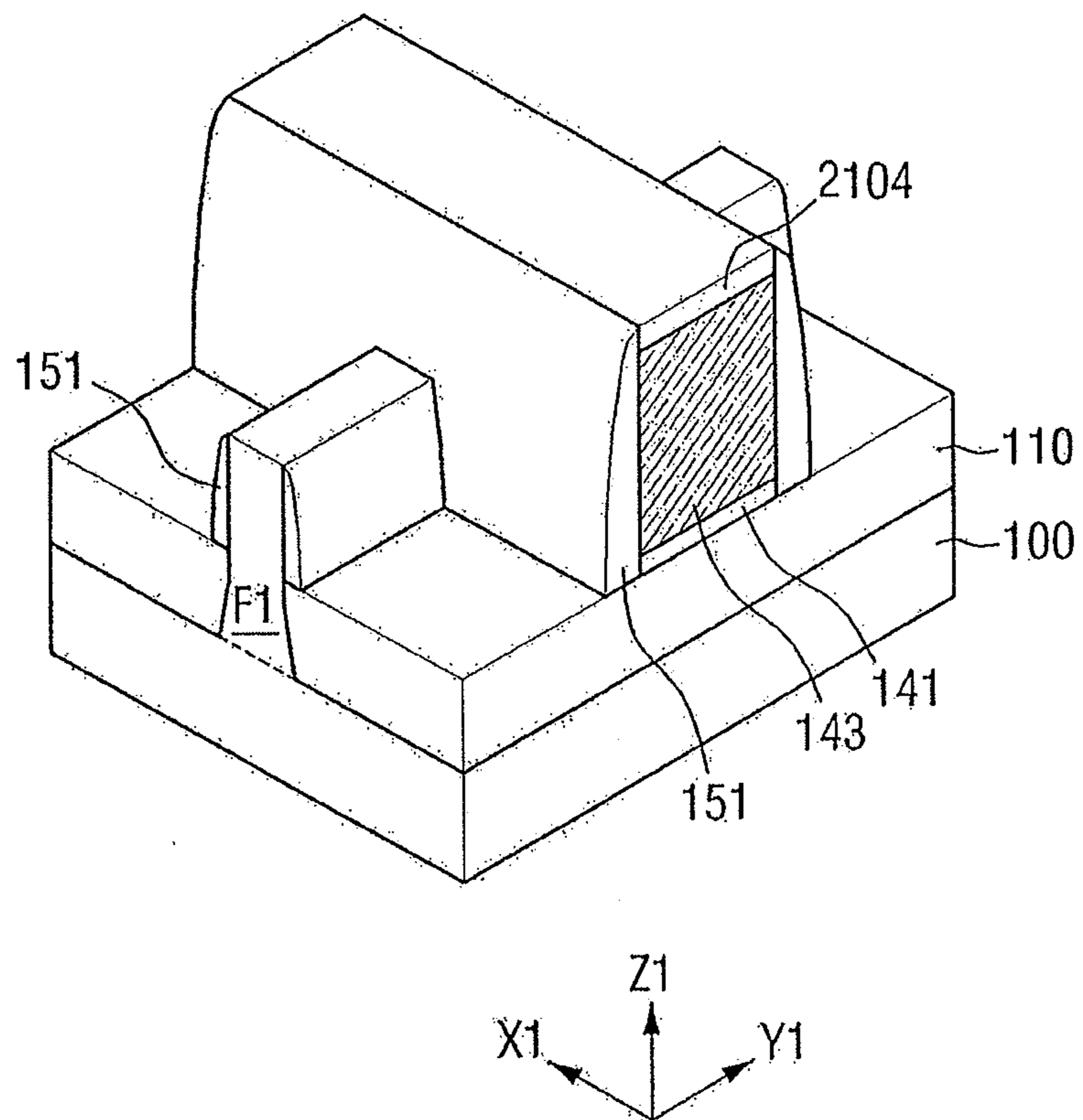


FIG. 19

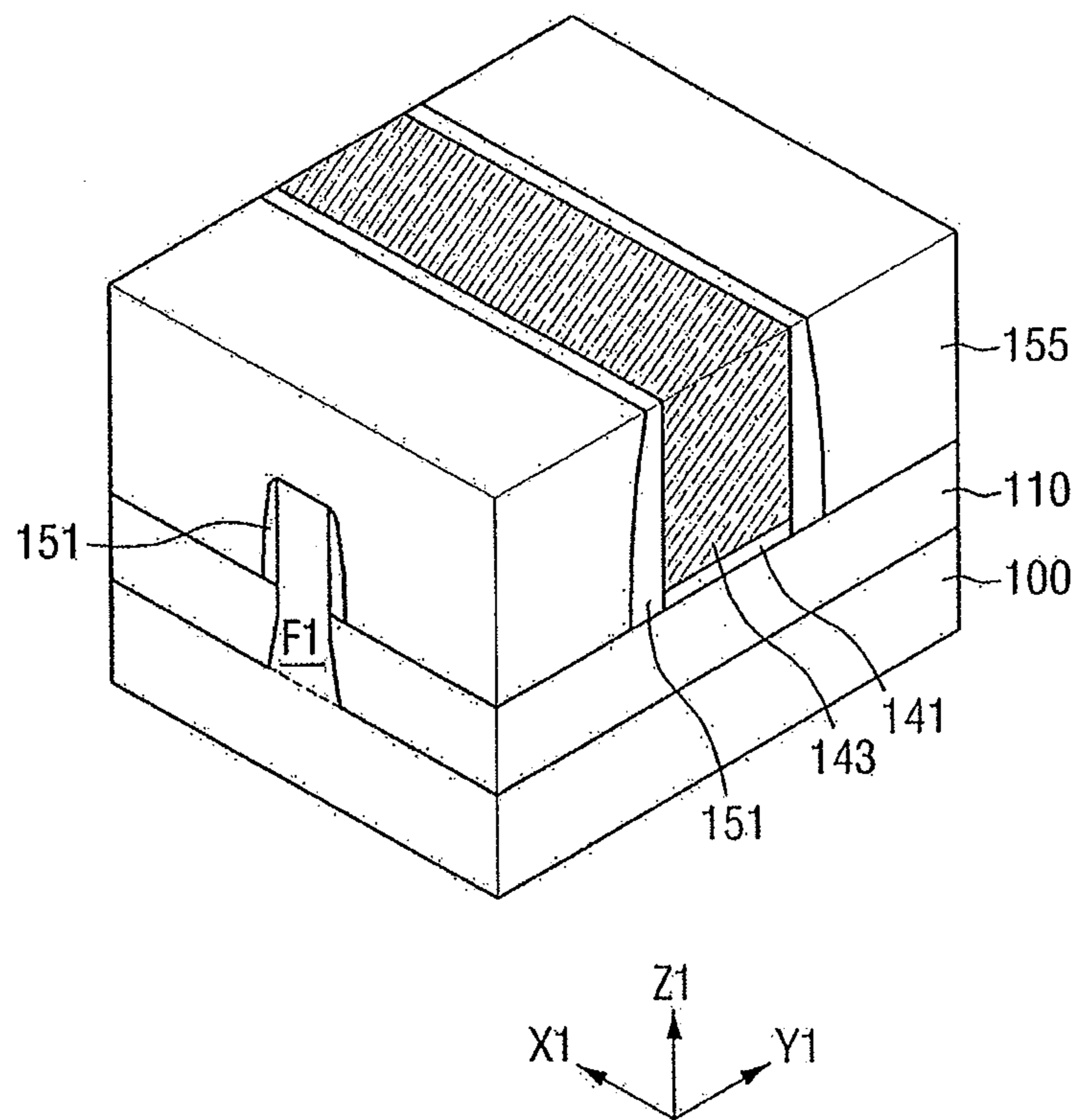


FIG. 20

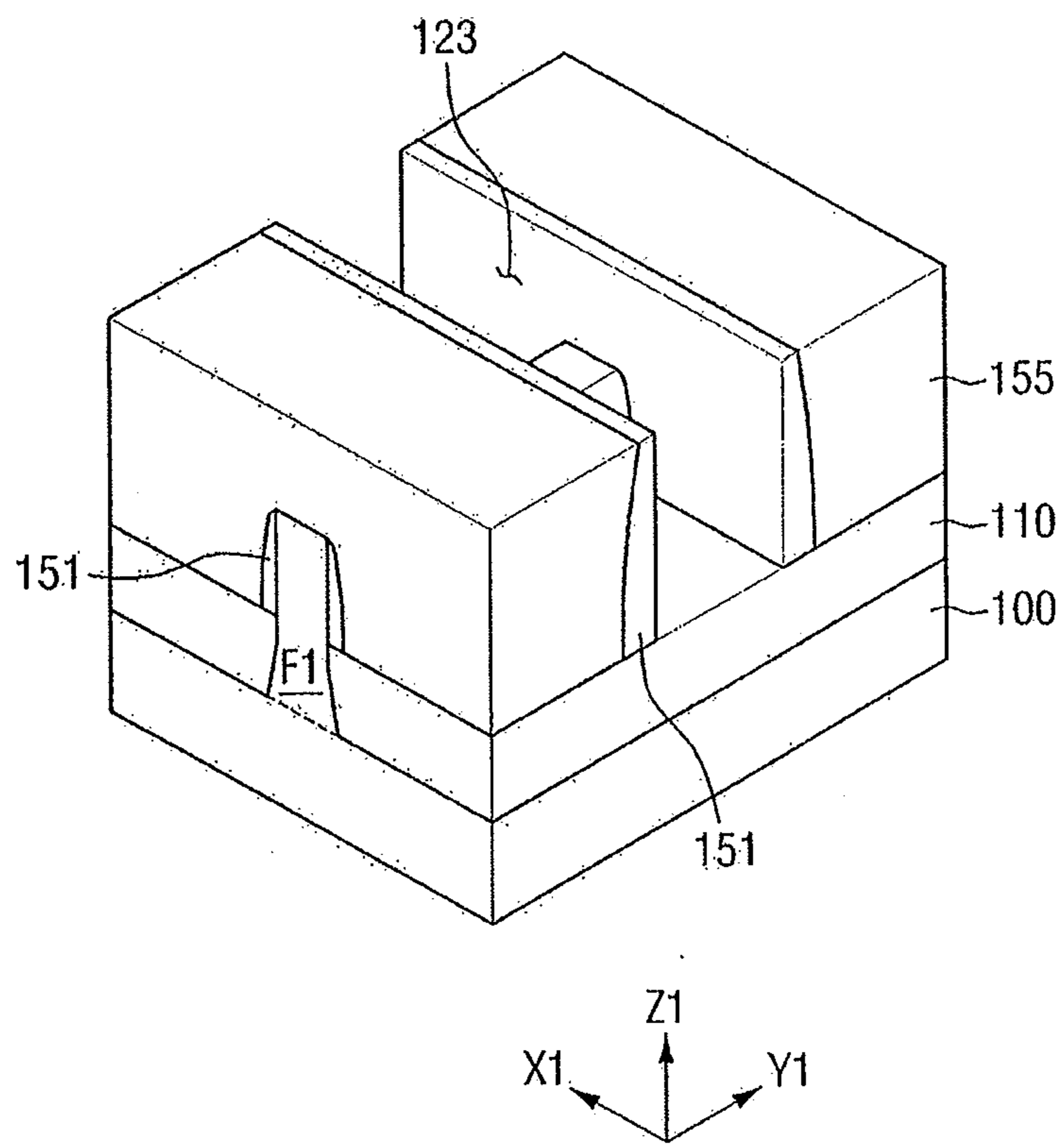


FIG. 21

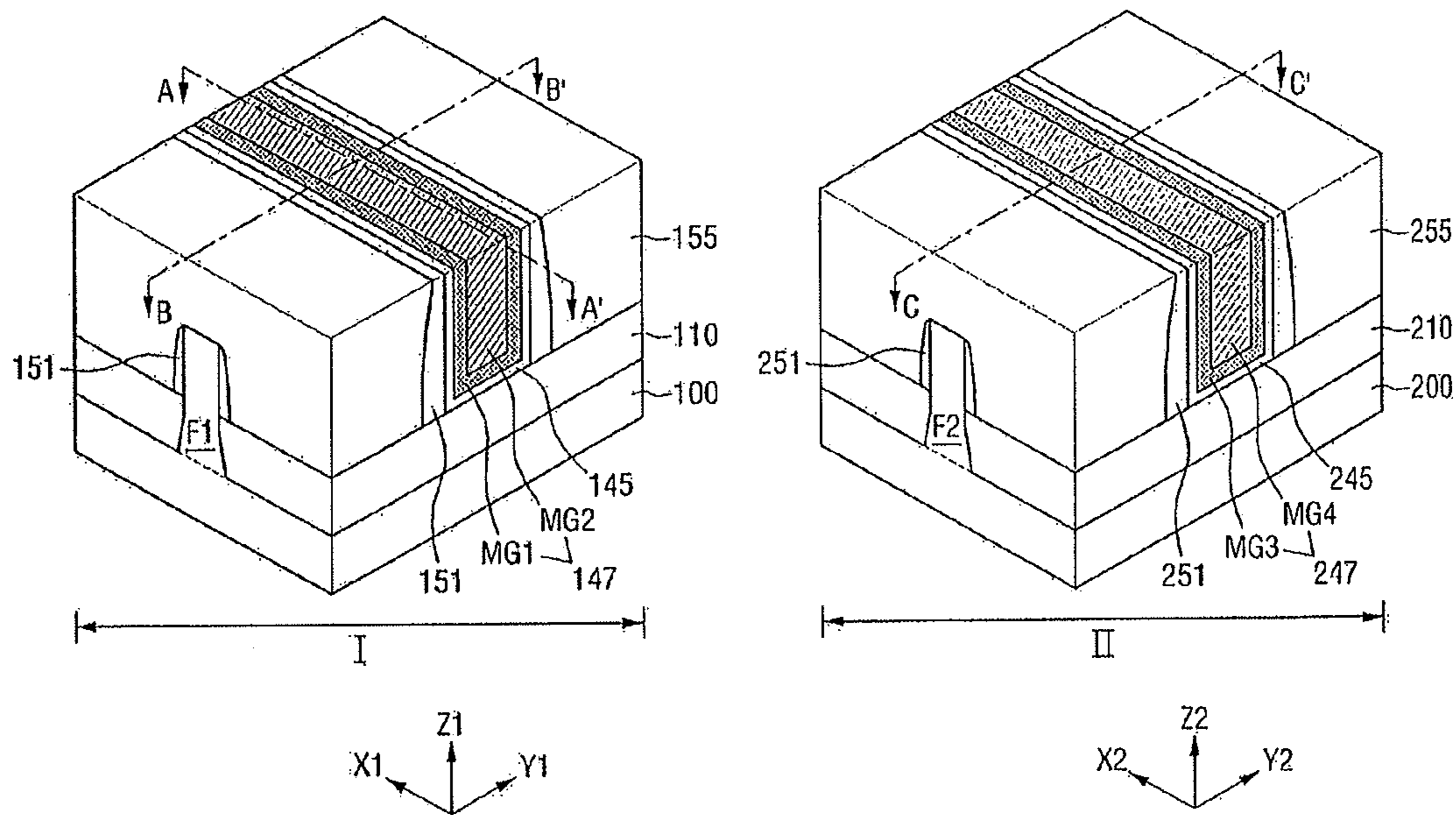


FIG. 22

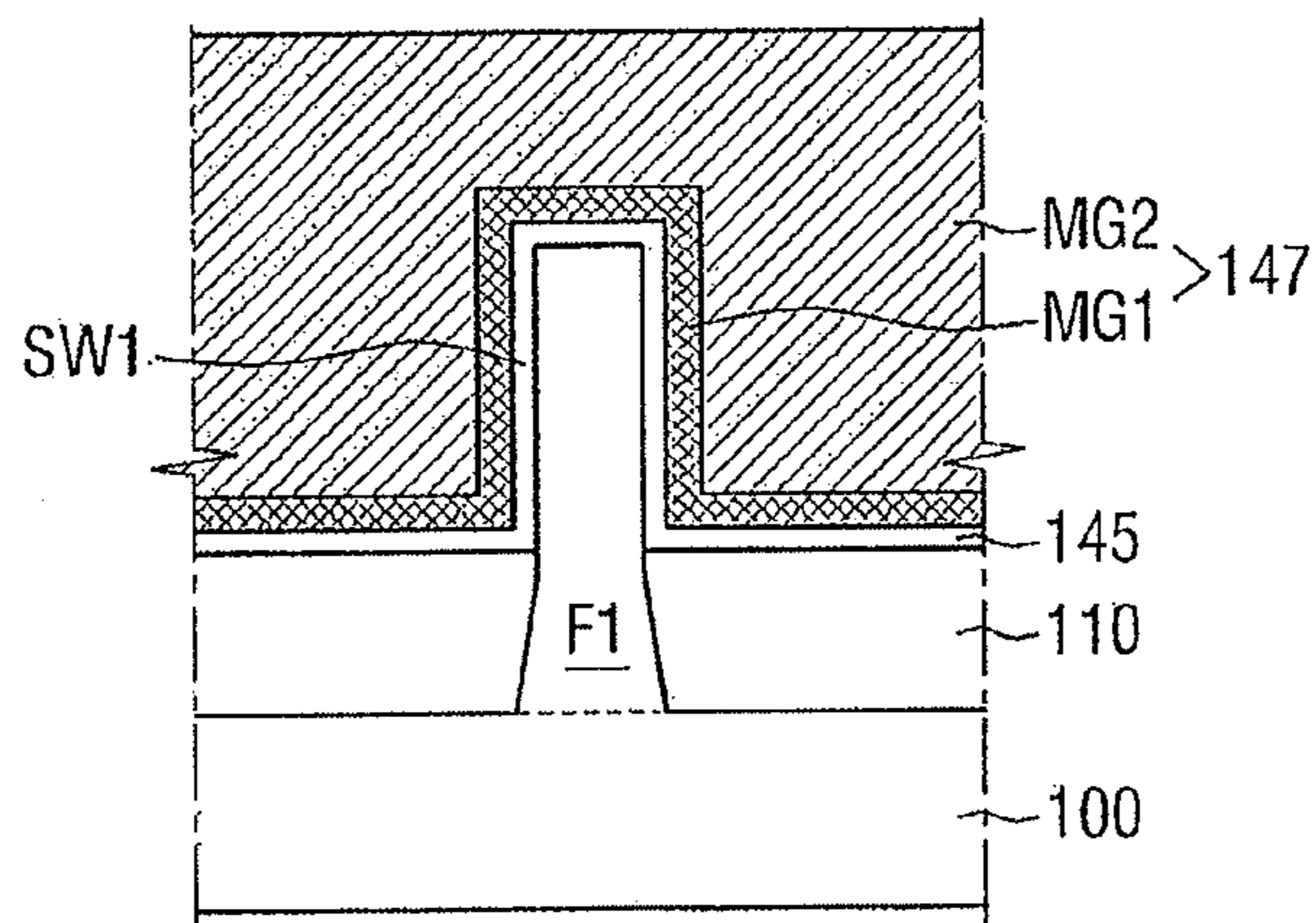




FIG. 23

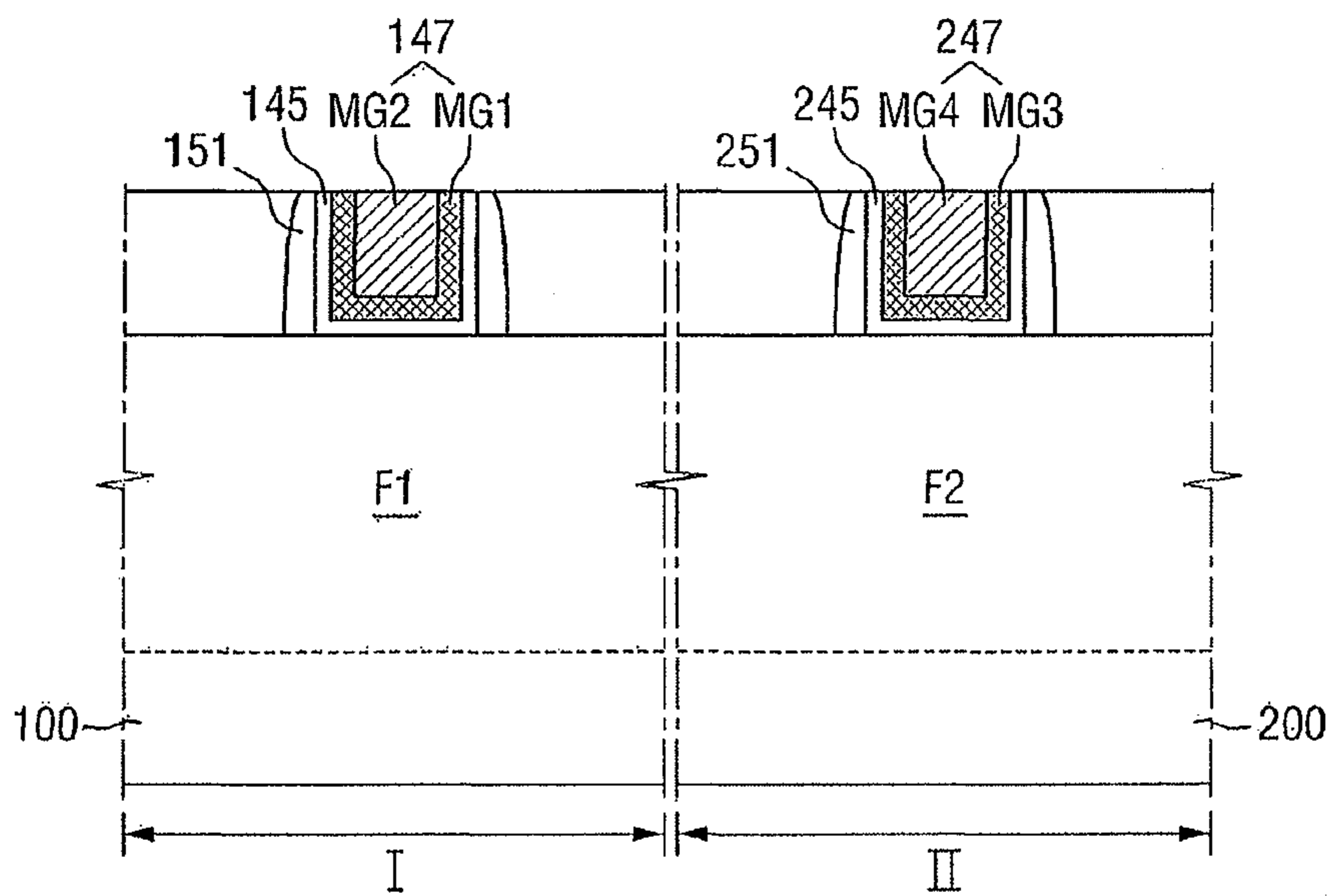


FIG. 24

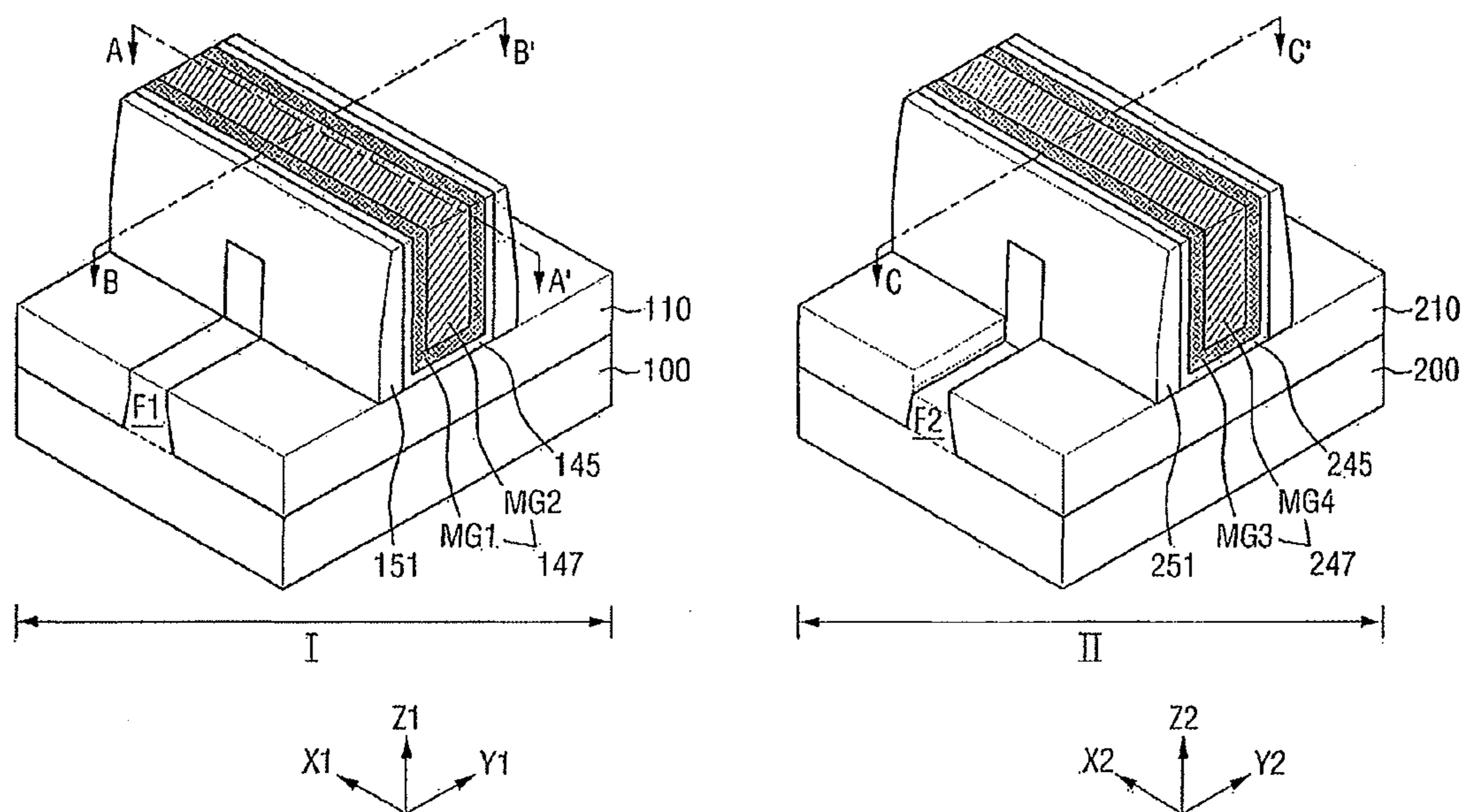


FIG. 25

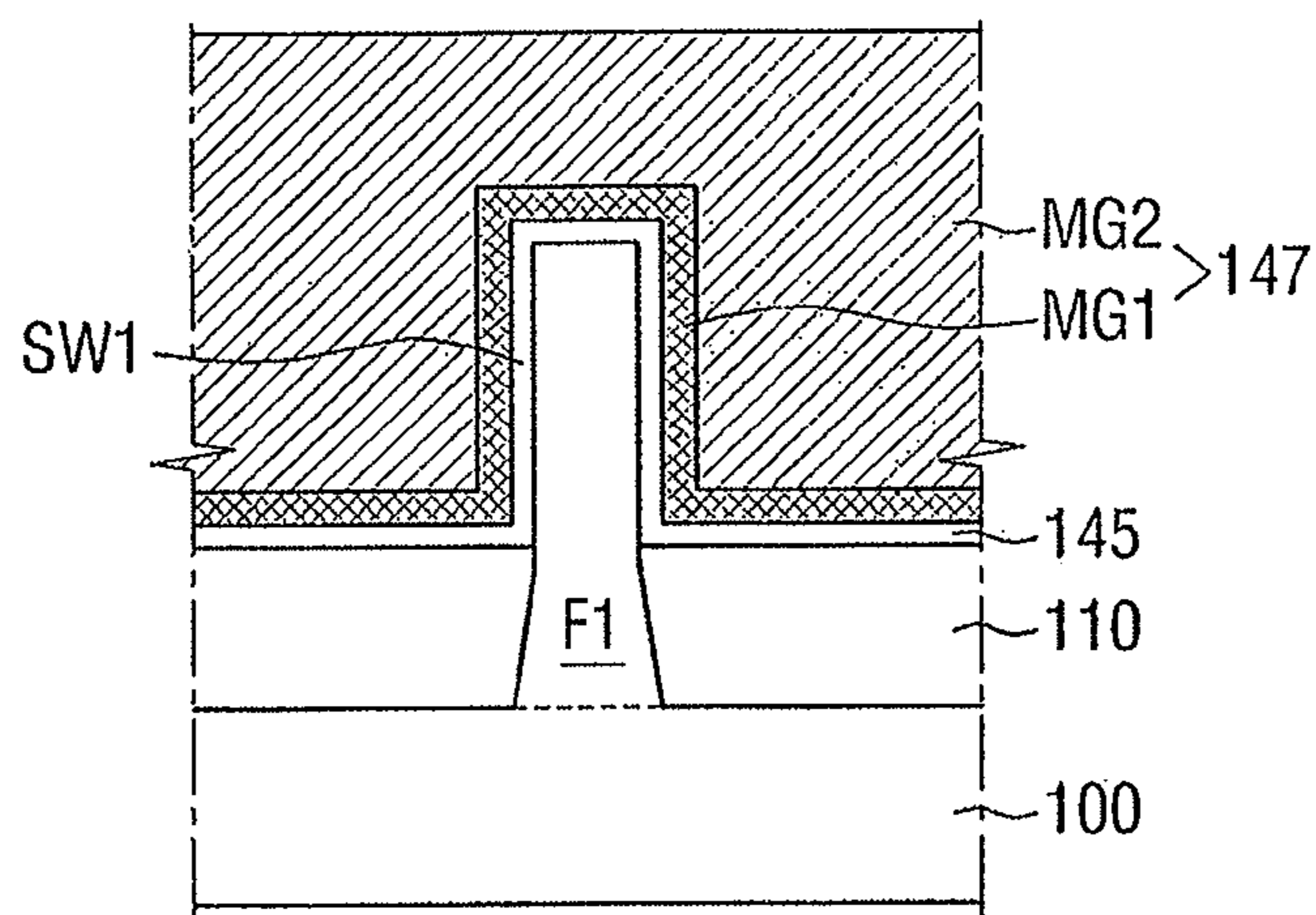


FIG. 26

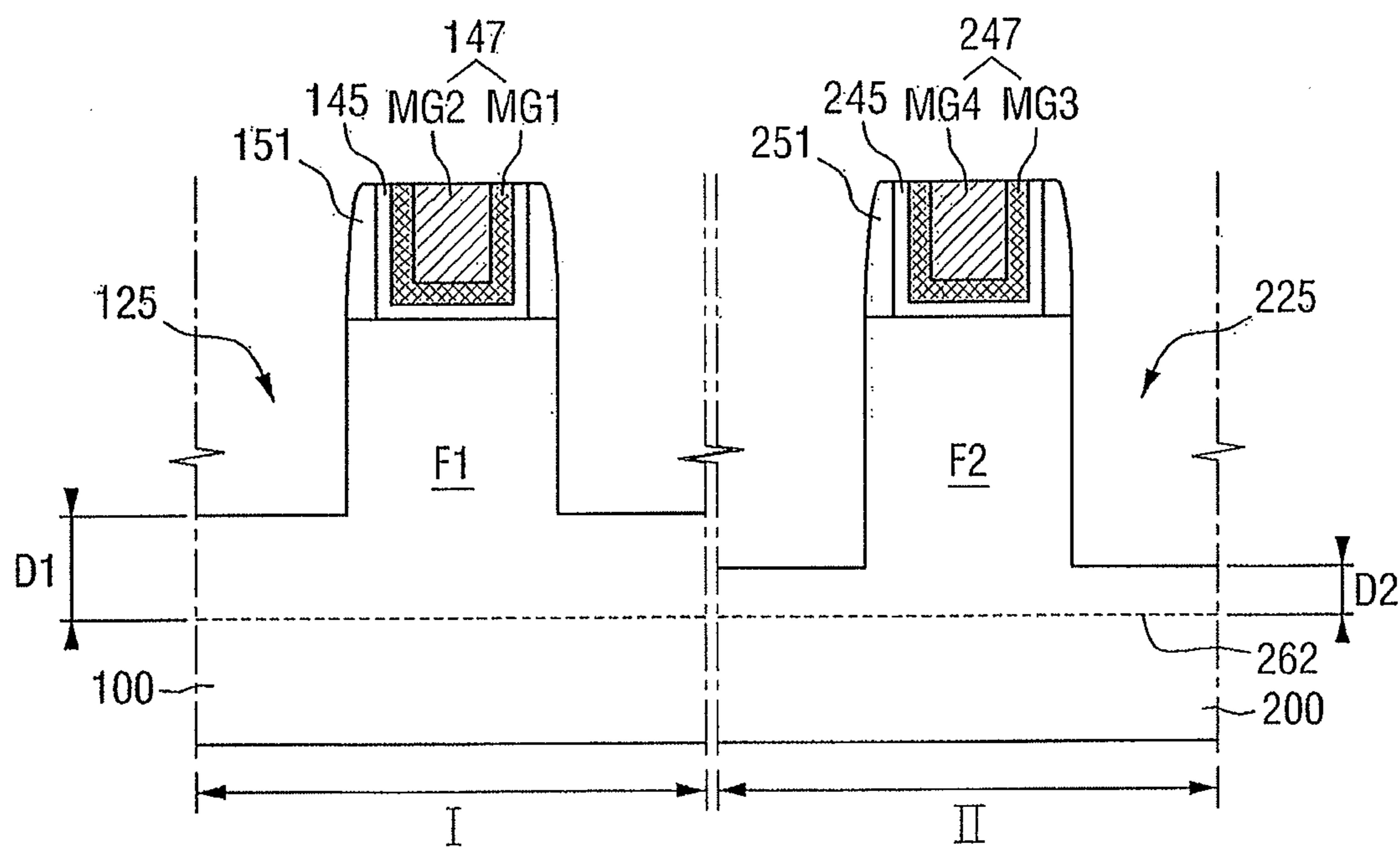


FIG. 27

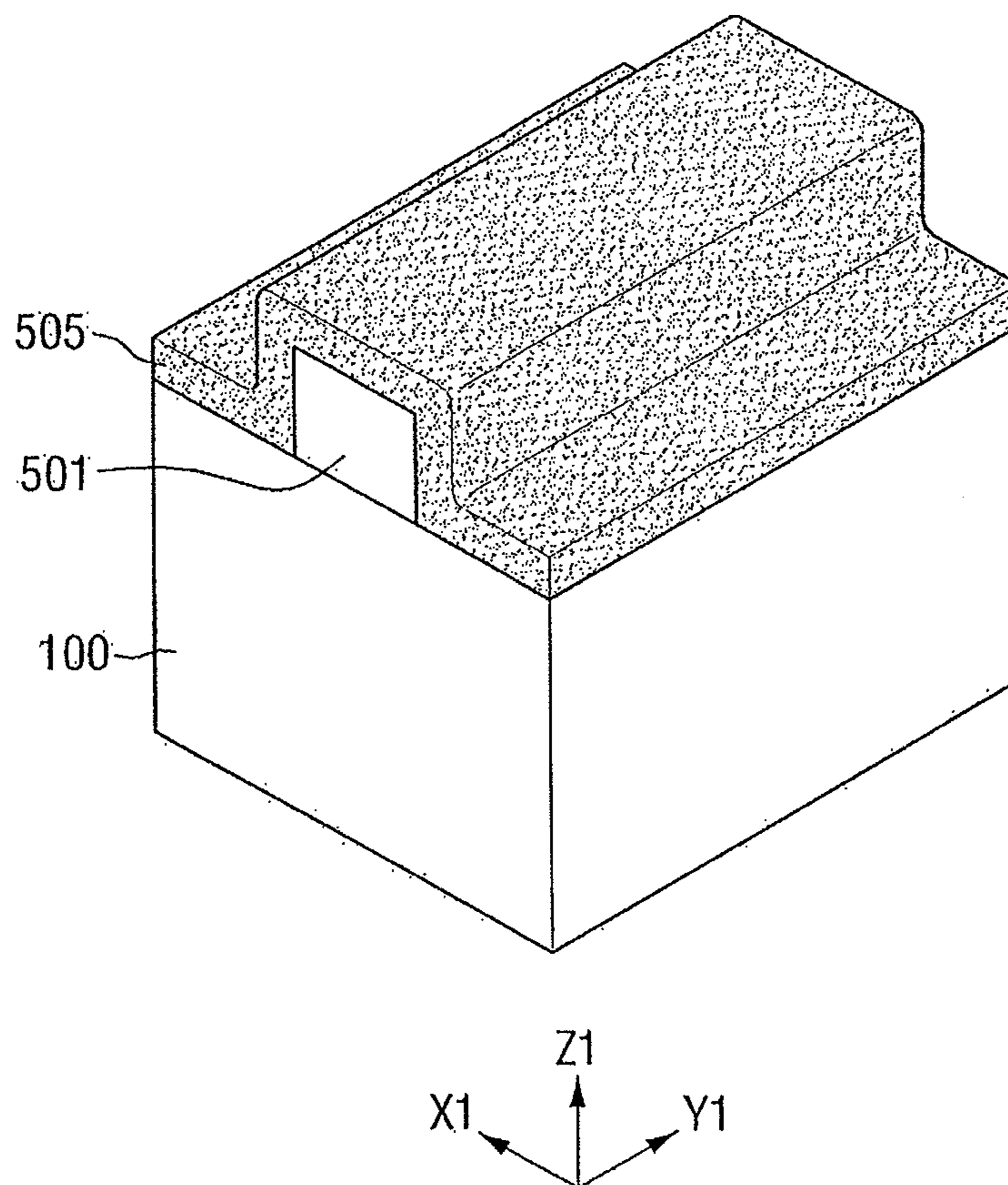


FIG. 28

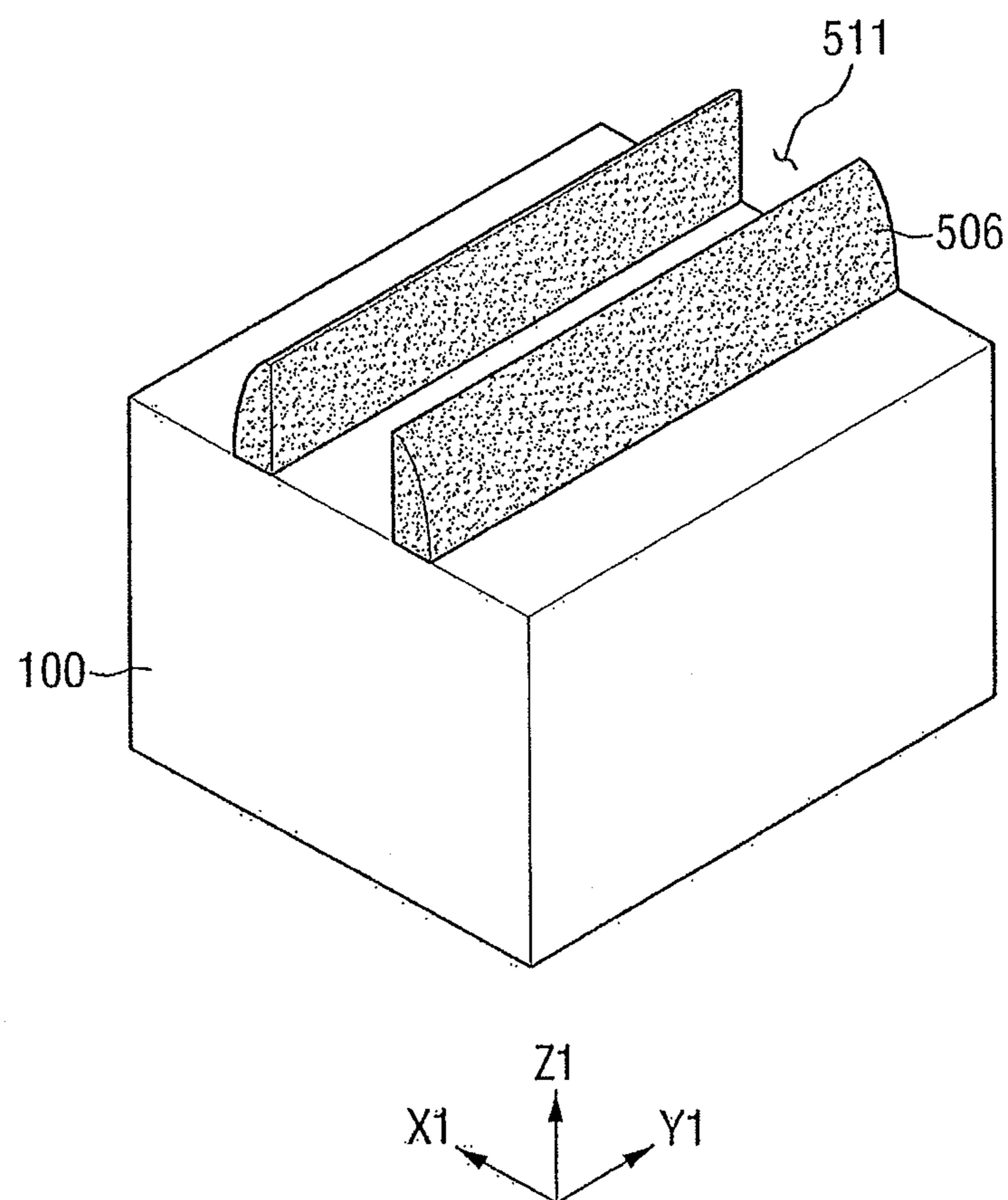


FIG. 29

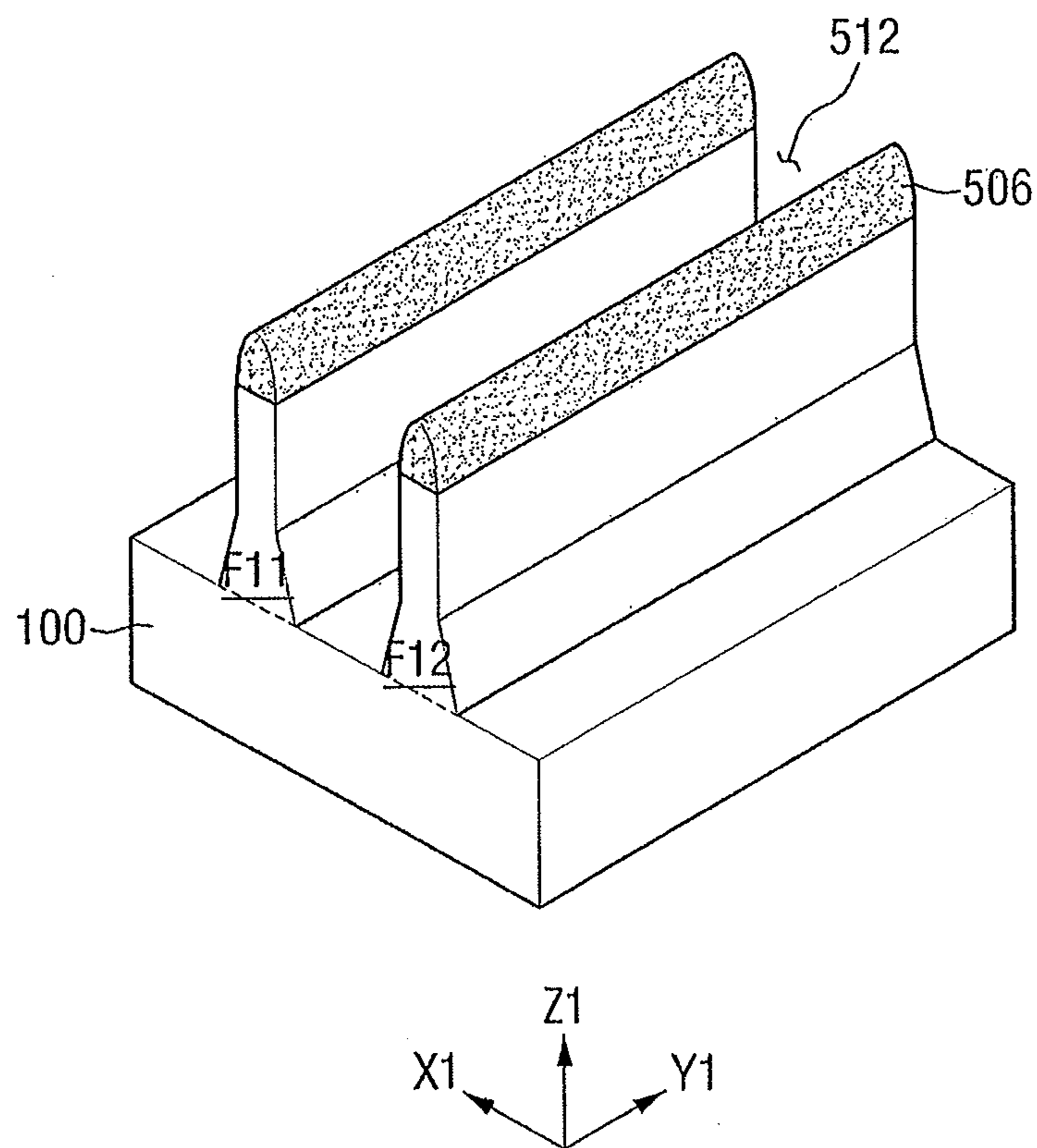


FIG. 30

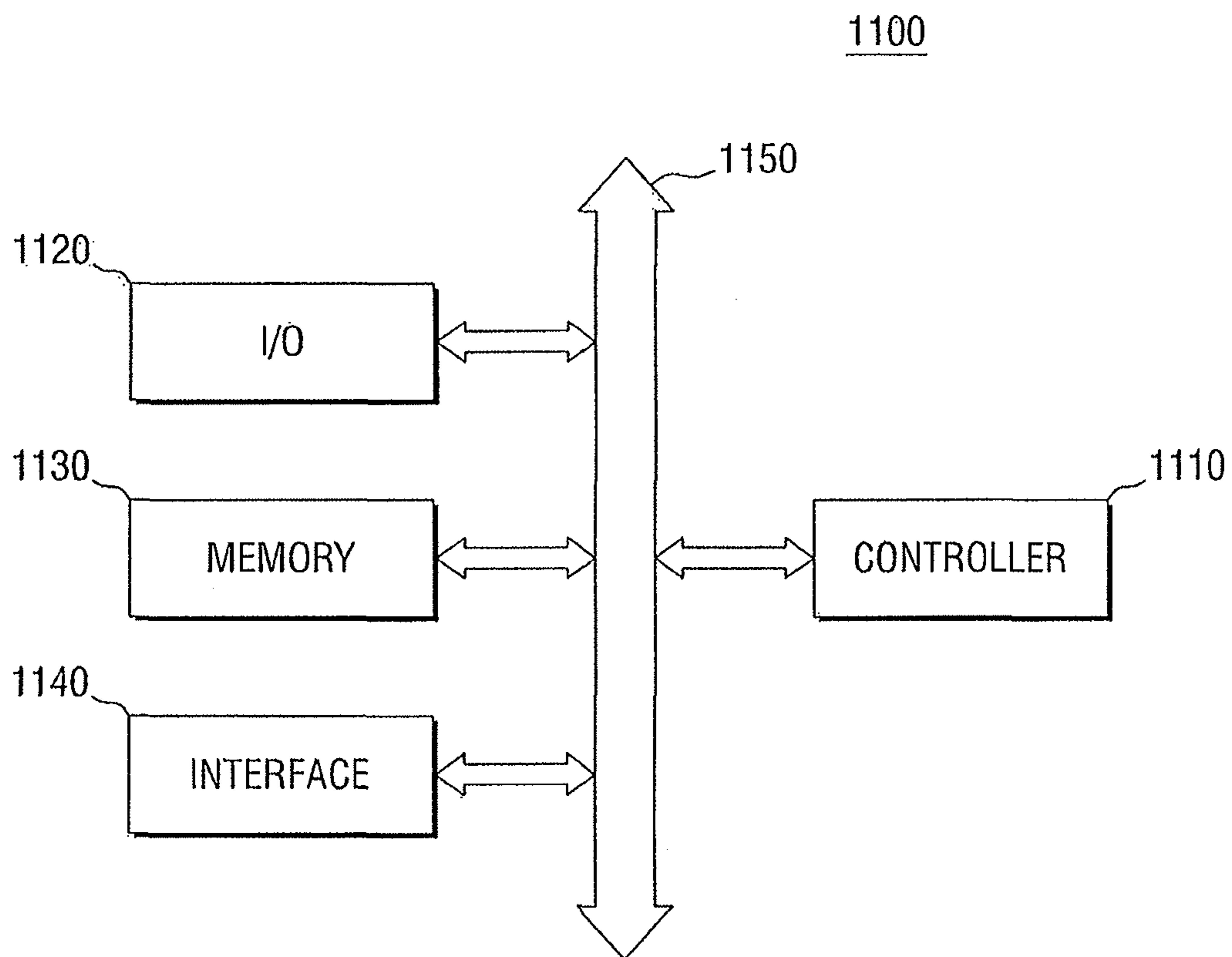


FIG. 31

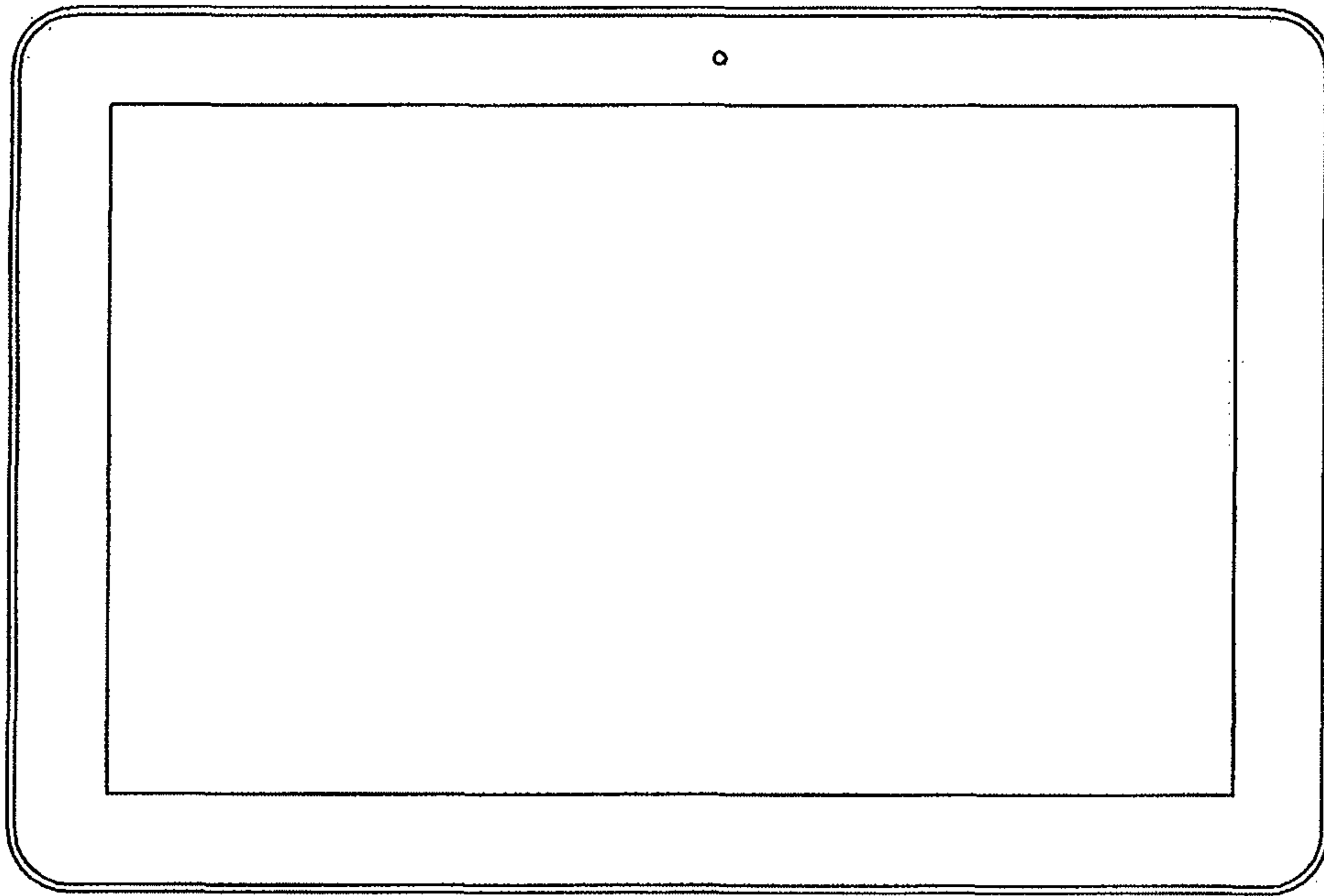
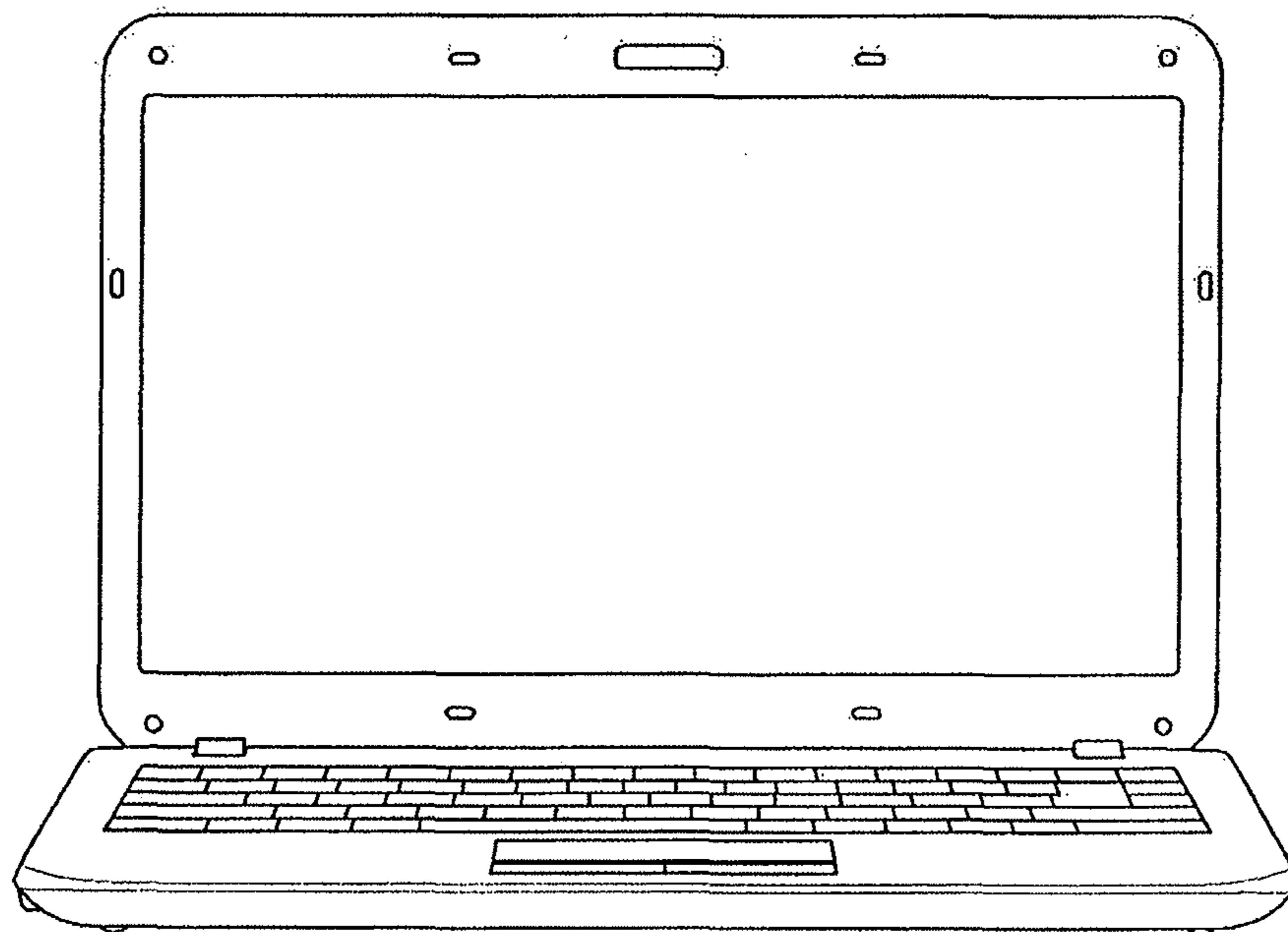


FIG. 32



## INTEGRATED CIRCUIT DEVICES

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.**

## CROSS-REFERENCE TO RELATED APPLICATION

This *reissue application is a division of U.S. Reissue patent application Ser. No. 16/432,340 filed Jun. 5, 2019, which is a Reissue of Ser. No. 9,673,099 B2 issued Jun. 6, 2017, matured from U.S. patent application Ser. No. 15/136,450 filed Apr. 22, 2016, and which is a divisional application based on [pending] application Ser. No. 14/162,052, filed Jan. 23, 2014, now U.S. Pat. No. 9,324,850, the entire contents of each which is hereby incorporated by reference.*

Korean Patent Application No. 10-2013-0020612, filed on Feb. 26, 2013, and entitled, "Integrated Circuit Devices and Fabricating Method Thereof," is incorporated by reference herein in its entirety.

## BACKGROUND

## 1. Field

One or more embodiments described herein relate to integrated circuit devices.

## 2. Description of the Related Art

Scaling techniques have been proposed for increasing the density of integrated circuit devices. One technique involves the use of a multi-gate transistor. Such a transistor may include a fin- or nanowire-shaped silicon body on a substrate. A gate is then formed on a surface of the silicon body.

Because a multi-gate transistor uses a three-dimensional (3D) channel, scaling may be achieved. In addition, current controlling capability can be improved without increasing a gate length of the multi-gate transistor. Further, a short channel effect (SCE), in which an electric potential of a channel region is affected by a drain voltage, can be effectively suppressed.

## SUMMARY

In accordance with one embodiment, an integrated circuit device includes a first fin-shaped transistor; and a second fin-shaped transistor, wherein first source/drain of the first fin-shaped transistor has a first thickness, and wherein second source/drain of the second fin-shaped transistor has a second thickness different from the first thickness.

Also, a distance ranging from a first bottom of a first fin of the first fin-shaped transistor to a first interface between the first fin and the first source/drain corresponds to a first distance, a distance ranging from a second bottom of a second fin of the second fin-shaped transistor to a second interface between the second fin and second source/drain corresponds to a second distance, and the first distance and the second distance are different.

Also, the first source/drain and the second source/drain may have substantially a same first lattice constant, and a first stress applied by the first source/drain to a first channel of the first fin-shaped transistor is different from a second stress applied by the second source/drain to a second channel of the second fin-shaped transistor. The first channel and

the second channel may have substantially a same second lattice constant different from the first lattice constant.

Also, the first fin-shaped transistor and the second fin-shaped transistor may be PMOS transistors, the first source/drain and the second source/drain may include SiGe, and the first channel and the second channel may include Si.

Also, the first fin-shaped transistor and the second fin-shaped transistor may be NMOS transistors, and the first source/drain and the second source/drain may include SiC, the first channel and the second channel including Si.

Also, an impurity concentration of the first source/drain may be different from an impurity concentration of the second source/drain.

In accordance with another embodiment, an integrated circuit device includes a substrate having a first region and a second region; a first fin-shaped transistor in the first region and including a first fin, a first gate electrode on and intersecting the first fin, first recesses on the first fin and at respective sides of the first gate electrode, and first source/drain in respective ones of the first recess; and a second fin-shaped transistor in the second region, the second fin-shaped transistor including a second fin, a second gate electrode intersecting the second fin on the second fin, second recesses on the second fin and at respective sides of the second gate electrode, and second source/drain in respective ones of the second recess, wherein the first source/drain has a first thickness and the second sources/drain has a second thickness different from the first thickness.

In accordance with another embodiment, an integrated circuit device includes a substrate having a first block and a second block; at least one first fin-shaped transistor in the first block; and at least one second fin-shaped transistor in the second block, wherein the first source/drain of the first fin-shaped transistor has a first thickness and wherein the second source/drain of the second fin-shaped transistor has a second thickness different from the first thickness.

In accordance with another embodiment, an integrated circuit device includes a substrate having a logic region and an SRAM region; a first fin-shaped transistor in the logic region, the first fin-shaped transistor including a first fin, first recesses on respective sides of the first fin, and first source/drain in respective ones of the first recesses; and a second fin-shaped transistor in the SRAM region, the second fin-shaped transistor including a second fin, second recesses on respective sides of the second fin, and second source/drain formed in respective ones of the second recesses, wherein a depth of the first recess is different from a depth of the second recess.

In accordance with another embodiment, an integrated circuit device includes a first nanowire-shaped transistor on a substrate, and a second nanowire-shaped transistor on the substrate, wherein a first thickness of a first source/drain of the first nanowire-shaped transistor is different from a second thickness of a second source/drain of the second nanowire-shaped transistor.

In accordance with another embodiment, an first nanowire-shaped transistor on a substrate and a second nanowire-shaped transistor on the substrate, wherein the first nanowire-shaped transistor includes multiple first nanowires stacked vertically and a first source/drain electrically connected to n first nanowires among the multiple first nanowires, where n is a natural number, and wherein the second nanowire-shaped transistor includes multiple second nanowires stacked vertically and a second source/drain electrically connected to m second nanowires among the multiple second nanowires, where m is a natural number.



The  $n$  first nanowires may be  $n$  first nanowires sequentially arranged from the topmost first nanowire, and the  $m$  second nanowires may be second nanowires sequentially arranged from the topmost second nanowire. The multiple first nanowires may be  $k$  first nanowires stacked one on another, and the multiple second nanowires may be second nanowires stacked one on another, where  $k$  is a natural number.

In accordance with another embodiment, a method of making an integrated circuit device includes providing a substrate having a first region and a second region; forming a first fin in the first region and forming a second fin in the second region; forming a first gate electrode intersecting the first fin in the first region and forming a second gate electrode intersecting the second fin in the second region, and forming a first recess in the first fin at either side of the first gate electrode in the first region and forming a second recess in the second fin at either side of the second gate electrode in the second region, wherein a depth of the first recess is different from a depth of the second recess.

In accordance with another embodiment, a device includes a first transistor having a first channel between first source/drain; and a second transistor having a second channel between second source/drain; wherein the first and second channels have fixed channel widths, and wherein the first transistor operates based on a first amount of current and the second transistor operates based on a second amount of current different from the first amount of current.

The first transistor may include a first fin including the first channel, and the second transistor may include a second fin including a second channel. The first source/drain may apply a first force to the first channel in the first fin, the second source/drain may apply a second force to the second channel in the second fin, wherein the first force is different from the second force, and wherein a difference between the first and second forces corresponding to a difference between the first and second amounts of current.

The first source/drain may apply the first force to the first channel based on a first impurity concentration, and the second source/drain may apply the second force to the second channel based on a second impurity concentration different from the first impurity concentration.

The first source/drain may apply the first force to the first channel based on a first size of the first source/drain, and the second source/drain may apply the second force to the second channel based on a second size of the second source/drain different from the first size. The first and second sizes may be different thicknesses.

The first transistor may have a first number of first fins, and the second transistor may have a second number of second fins different from the first number of fins, wherein the first number is at least one and wherein the first number of fins corresponds to the first amount of current and the second number of fins corresponds to a second amount of current.

The first transistor may have a first number of nanowires which includes the first channel, and the second transistor may have a second number of nanowires which includes a second channel, wherein the first number of nanowires is at least one and wherein the first amount of current based on the first number of nanowires and the second amount of current based on the second number of nanowires.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Features will become apparent to those of ordinary skill in the art by describing in detail exemplary embodiments with reference to the attached drawings in which:

FIG. 1 illustrates a first embodiment of an integrated circuit device;

FIG. 2 illustrates a view along section line A-A in FIG. 1;

FIG. 3 illustrates a view along section lines B-B and C-C in FIG. 1;

FIG. 4 illustrates a second embodiment of an integrated circuit device;

FIG. 5 illustrates a third embodiment of an integrated circuit device;

FIG. 6 illustrates a fourth embodiment of an integrated circuit device;

FIG. 7 illustrates a fifth embodiment of an integrated circuit device;

FIG. 8 illustrates a sixth embodiment of an integrated circuit device;

FIGS. 9A and 9B illustrate a circuit view and a layout view for explaining an integrated circuit device according to a seventh embodiment, FIG. 9C illustrates only multiple fins and multiple gate electrodes from the layout view of FIG. 9B, and FIG. 9D illustrates a cross-sectional view along section lines D-D and E-E of FIG. 9B;

FIGS. 10A to 10C illustrate eighth embodiments of integrated circuit devices;

FIGS. 11A and 11B illustrate conceptual diagrams of ninth and tenth embodiments of integrated circuit;

FIG. 12 illustrates an eleventh embodiment of an integrated circuit device;

FIGS. 13A and 13B illustrate twelfth embodiments of integrated circuit;

FIGS. 14 to 26 illustrate a first embodiment of a method for making an integrated circuit device 1;

FIGS. 27 to 29 illustrate a method for forming fins that can be used in a method for making integrated circuit devices;

FIG. 30 illustrates an embodiment of an electronic system including any of the aforementioned embodiments of an integrated circuit device; and

FIGS. 31 and 32 illustrate an embodiment of a semiconductor system including any one of the aforementioned embodiments of an integrated circuit device.

#### DETAILED DESCRIPTION

Example embodiments are described more fully hereinafter with reference to the accompanying drawings; however, they may be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey exemplary implementations to those skilled in the art.

In the drawing figures, the dimensions of layers and regions may be exaggerated for clarity of illustration. It will also be understood that when a layer or element is referred to as being "on" another layer or substrate, it can be directly on the other layer or substrate, or intervening layers may also be present. Further, it will be understood that when a layer is referred to as being "under" another layer, it can be directly under, and one or more intervening layers may also be present. In addition, it will also be understood that when a layer is referred to as being "between" two layers, it can be the only layer between the two layers, or one or more intervening layers may also be present. Like reference numerals refer to like elements throughout.

FIG. 1 illustrates a first embodiment of an integrated circuit device, FIG. 2 illustrates a cross-sectional view taken

along line A-A of FIG. 1, and FIG. 3 illustrates a cross-sectional view taken along lines B-B and C-C of FIG. 1.

Referring to FIGS. 1 to 3, a first fin-shaped transistor **101** is formed in a first region I, and a second fin-shaped transistor **201** is formed in a second region II. The first region I and the second region II may be regions spaced apart from each other or connected to each other. For example, the first region I may be an SRAM region, and the second region II may be a logic region. Alternatively, the first region I may be a region where a pull-up transistor of SRAM is formed, and the second region II may be a region where a pull-down transistor of a RAM or a pass transistor is formed.

Stress applied to a channel of the first fin-shaped transistor **101** and stress applied to a channel of the second fin-shaped transistor **201**, are different from each other. When appropriate stress is applied to a channel, the mobility of carriers may be improved and the amount of current may be increased. An amount of strain applied to a channel may vary according to how close to the channel the stress is applied. In this embodiment, in order to adjust the magnitude of applied stress, a first thickness **T1** of a first source/drain **161** of the first fin-shaped transistor **101** and a second thickness **T2** of a second source/drain **261** of the second fin-shaped transistor **201** are adjusted to be different from each other.

The first fin-shaped transistor **101** may include a first fin **F1**, a first gate electrode **147**, a first recess **125**, and a first source/drain **161**. The first fin **F1** may extend lengthwise in a second direction **Y1**. The first fin **F1** may include part of the substrate **100** and may include an epitaxial layer grown from the substrate **100**. An isolation film **110** may cover side surfaces of the first fin **F1**.

The first gate electrode **147** may be formed on the first fin **F1**, for example, to intersect the first fin **F1**. The first gate electrode **147** may extend in a first direction **X1**.

The first gate electrode **147** may include metal layers **MG1** and **MG2**. As shown, the first gate electrode **147** may include two or more metal layers **MG1** and **MG2**. The first metal layer **MG1** may function to adjust a work function, and the second metal layer **MG2** may function to fill a space formed by the first metal layer **MG1**. For example, the first metal layer **MG1** may include at least one of TiN, TaN, TiC, or TaC. The second metal layer **MG2** may include W or Al. Alternatively, the first gate electrode **147** may include a material other than a metal, such as Si or SiGe. The first gate electrode **147** may be formed by, for example, a replacement process. That is, the first gate electrode **147** may have a gate last structure. The first gate electrode **147** may have, for example, a gate first structure.

The first gate insulation layer **145** may be formed between the first fin **F1** and the first gate electrode **147**. As shown FIG. 2, the first gate insulation layer **145** may be formed on a top surface and upper portions of side surfaces of the first fin **F1**. In addition, the first gate insulation layer **145** may be disposed between the first gate electrode **147** and the isolation film **110**. The first gate insulation layer **145** may include a high-k material having a higher dielectric constant than silicon oxide. For example, the first gate insulation layer **145** may include HfO<sub>2</sub>, ZrO<sub>2</sub> or Ta<sub>2</sub>O<sub>5</sub>.

The first recess **125** may be formed in the first fin **F1** at either side of the first gate electrode **147**. The first source/drain **161** is formed in the first recess **125** and may be an elevated source/drain. The first source/drain **161** and the first gate electrode **147** may be insulated from each other by a spacer **151**. The spacer **151** may include at least one of nitride or oxynitride.

In a case where the first fin-shaped transistor **101** is a PMOS transistor, the first source/drain **161** may include a compressive stress material. For example, the compressive stress material may be a material having a larger lattice constant than silicon (Si), for example, SiGe. The compressive stress material may improve the mobility of carriers of a channel region by applying compressive stress to the first fin **F1**.

However, in a case where the first fin-shaped transistor **101** is an NMOS transistor, the first source/drain **161** may include the same material as the substrate **100** or a tensile stress material. For example, when the substrate **100** includes Si, the first source/drain **161** may include Si or a material having a smaller lattice constant than Si (e.g., SiC).

The substrate **100** may include one or more semiconductor materials selected from the group consisting of Si, Ge, SiGe, GaP, GaAs, SiC, SiGeC, InAs and InP. Alternatively, the substrate **100** may be a silicon on insulator (SOI) substrate.

The second fin-shaped transistor **201** may include a second fin **F2**, a second gate electrode **247**, a second recess **225**, and a second source/drain **261**. The second gate electrode **247** may be formed on the second fin **F2**, for example, to intersect the second fin **F2**. The second recess **225** may be formed in the second fin **F2** at either side of the second gate electrode **247**. The second source/drain **261** may be formed in the second recess **225**. The second fin-shaped transistor **201** may be similar to the first fin-shaped transistor **101**, except for certain differences as described herein.

In FIG. 1, for the sake of convenient explanation, the first fin **F1** and the second fin **F2** are illustrated to extend lengthwise in second directions **Y1** and **Y2** to be parallel to each other. In other embodiments, the fins may not be parallel. For example, the first fin **F1** may extend lengthwise in the second direction **Y1**, and the second fin **F2** may extend lengthwise in the first direction **X2**.

Likewise, the first gate electrode **147** and the second gate electrode **247** are illustrated to extend lengthwise in the first directions **X1** and **X2** to be parallel to each other. In other embodiments, the gate electrodes may not be parallel. For example, the first gate electrode **147** may extend lengthwise in the first direction **X1**, and the second gate electrode **247** may extend lengthwise in the second direction **Y2**.

The first fin-shaped transistor **101** and the second fin-shaped transistor **201** may have the same conductivity type (e.g., a P or an N type). Alternatively, the first fin-shaped transistor **101** may be of a first conductivity type (e.g., a P type) and the second fin-shaped transistor **201** may be of a second conductivity type (e.g., an N type).

In the figures, reference numeral **201** may denote a substrate, reference numeral **245** may denote a second gate insulation layer, reference numeral **251** may denote a second spacer, reference symbol **MG3** may denote a third metal layer, and reference symbol **MG4** may denote a fourth metal layer.

The first recess **125** and the second recess **225** may be filled with metal, instead of a semiconductor material. That is to say, the first source/drain **161** and the second source/drain **261** may include a metallic material, not a semiconductor material, such as Si, SiGe or SiC.

Referring to FIG. 3, as described above, the first thickness **T1** of the first source/drain **161** of the first fin-shaped transistor **101** is different from the second thickness **T2** of the second source/drain **261** of the second fin-shaped transistor **201**. As shown in FIG. 3, the first thickness **T1** may be smaller than the second thickness **T2**.

In other words, a first distance **D1** refers to a distance ranging from a first bottom **162** of the first fin **F1** of the first

fin-shaped transistor **101** to a first interface **163** between the first fin **F1** and the first source/drain **161**. A second distance **D2** refers to a distance ranging from a second bottom **262** of the second fin **F2** of the second fin-shaped transistor **201** to a second interface **263** between the second fin **F2** and the second source/drain **261**. The first distance **D1** and second distance **D2** may be different from each other. Here, the term “distance ranging from a to b” means the shortest distance between a and b. As shown, the second distance **D2** may be shorter than the first distance **D1**.

In other words, a depth of the first recess **125** of the first fin-shaped transistor **101** and a depth of the second recess **225** of the second fin-shaped transistor **201** may be different from each other. The first source/drain **161** may be formed in the first recess **125** and the second source/drain **261** may be formed in the second recess **225**. Therefore, if the first recess **125** and the second recess **225** are formed to have different depths, the first thickness **T1** of the first source/drain **161** may be different from the second thickness **T2** of the second source/drain **261**.

The isolation film **110** may have a thickness **D1** (see FIG. 2). As shown, the first recess **125** may be formed to reach a top surface of the isolation film **110** and the second recess **225** may be formed to be deeper than the top surface of the isolation film **110**. The second recess **225** is deeper than the first recess **125**.

For example, when the first fin-shaped transistor **101** and the second fin-shaped transistor **201** are both P-type transistors, the substrate **100** may include Si and the first source/drain **161** and the second source/drain **261** may include SiGe. In this case, since SiGe has a larger lattice constant than Si, the first source/drain **161** may apply compressive stress to a channel of the first fin-shaped transistor **101** and the second source/drain **261** may apply compressive stress to a channel of the second fin-shaped transistor **201**.

However, since the first thickness **T1** of the first source/drain **161** is smaller than the second thickness **T2** of the second source/drain **261**, a volume of the first source/drain **161** is smaller than that of the second source/drain **261**. Therefore, the compressive stress applied from the first source/drain **161** to the channel of the first fin-shaped transistor **101** may be smaller than the compressive stress applied from the second source/drain **261** to the channel of the second fin-shaped transistor **201**. Therefore, a driving current amount of the first fin-shaped transistor **101** may be greater than that of the second fin-shaped transistor **201**.

In a case of a fin having a very small width (e.g., 20 nm or less), the fin may not be formed using a general photo process. A sidewall image transfer (SIT) process, for example, may be used for a fin having a predetermined width is repeatedly formed. In this case, it is difficult to effectively adjust a channel width. That is to say, in a case of a general planar transistor, it is easy to control the current amount by varying the channel width. However, in a case of a fin-shaped transistor using a fin formed through the SIT process, it may be more difficult to control the current amount because the fin has a fixed channel width.

In the integrated circuit device according to the first embodiment, the current amounts of the fin-shaped transistors **101** and **201** can be easily controlled by adjusting the thicknesses **T1** and **T2** of the first and second sources/drains **161** and **261**.

FIG. 4 illustrates a cross-sectional view of a second embodiment of an integrated circuit device. This embodiment may be similar to the aforementioned embodiment, except for several differences noted as follows.

Referring to FIG. 4, assuming that an isolation film **110** has a thickness **D1** (see FIG. 2), a first recess **125** is formed to extend over a top surface of the isolation film **110**, and a second recess **225** may be formed to be deeper than the top surface of the isolation film **110**. The second recess **225** may be formed to be deeper than the first recess **125**.

A third thickness **T3** of the first source/drain **161** of the first fin-shaped transistor **102** may be different from the second thickness **T2** of the second source/drain **261** of the second fin-shaped transistor **202**. The third thickness **T3** may be smaller than the first thickness **T1** (see FIG. 3).

A third distance **D3** refers to a distance ranging from a first bottom **162** of a first fin **F1** of a first fin-shaped transistor **102** to a first interface **163** between the first fin **F1** and a first source/drain **161**. A second distance **D2** refers to a distance ranging from a second bottom **262** of a second fin **F2** of a second fin-shaped transistor **202** to a second interface **263** between the second fin **F2** and a second source/drain **261**. The third distance **D3** and the second distance **D2** may be different from each other. In addition, the third distance **D3** may be longer than the first distance **D1** (see FIG. 3).

FIG. 5 illustrates a cross-sectional view of a third embodiment of an integrated circuit device. Referring to FIG. 5, assuming that an isolation film **110** has a thickness **D1** (see FIG. 2), both of a first recess **125** and a second recess **225** may be formed to be deeper than a top surface of the isolation film **110**. In addition, the second recess **225** is deeper than the first recess **125**.

A fourth thickness **T4** and a second thickness **T2** may be different from each other. The fourth thickness **T4** may be larger than the first thickness **T1** (see FIG. 3). However, the fourth thickness **T4** may be smaller than the second thickness **T2**.

A fourth distance **D4** and a second distance **D2** may be different from each other. The fourth distance **D4** may be smaller than the first distance **D1** (see FIG. 3). In addition, the fourth distance **D4** may be larger than the second distance **D2**.

FIG. 6 illustrates a cross-sectional view of a fourth embodiment of an integrated circuit device. Referring to FIG. 6, a first stress layer **169** may be formed on a first fin-shaped transistor **104** and a second stress layer **269** may be formed on a second fin-shaped transistor **204**. The stress layers **169** and **269** may be, for example, SiN layers. In the case where SiN layers are used, the type of stress applied by the stress layers **169** and **269** to the channel may be determined according to the N—H to Si—H bonding ratio in the SiN layer. For example, if the N—H bonding/Si—H bonding ratio is in a range of 1 to 5, the SiN layer may apply tensile stress. If the N—H bonding/Si—H bonding ratio is in a range of 5 to 20, the SiN layer may apply compressive stress.

For example, when the first fin-shaped transistor **104** and the second fin-shaped transistor **204** are both PMOS transistors, a driving current amount of the second fin-shaped transistor **202** may be greater than that of the first fin-shaped transistor **102**. The current amounts of the first fin-shaped transistor **102** and the second fin-shaped transistor **202** may also be increased due to the first stress layer **169** and the second stress layer **269**.

FIG. 7 illustrates a cross-sectional view of a fifth embodiment of an integrated circuit device. Referring to FIG. 7, stress applied from a first spacer **151** to a channel of a first fin-shaped transistor **105** and stress applied from a second spacer **251** to a channel of a second fin-shaped transistor **205** may be different from each other. In one embodiment, the materials used to form the first spacer **151** and the second

spacer **251** may be different from each other. For example, insulating layers **151a** and **151b** of the first spacer **151** and an insulating layer **251b** of the second spacer **251** may be materials which do not apply stress to a channel. However, the second spacer **251d** may be a material applying stress to a channel of the second fin-shaped transistor **203a**. As the result, the driving current amounts of the first fin-shaped transistor **105** and the second fin-shaped transistor **205** may be controlled to be different from each other.

FIG. **8** illustrates a cross-sectional view of a sixth embodiment of an integrated circuit device. Referring to FIG. **8**, a first fin-shaped transistor **106** and a second fin-shaped transistor **206** may be of the same conductivity type. An impurity concentration of a first source/drain **161** formed in a first recess **125** and an impurity concentration of a second source/drain **261** formed in a second recess **225** may be different from each other. For example, if the impurity concentration of the second source/drain **261** is greater than that of the first source/drain **161**, resistance of the second source/drain **261** may be smaller than resistance of the first source/drain **161**. Therefore, a driving current amount of the second fin-shaped transistor **206** may be greater than that of the first fin-shaped transistor **106**. That is to say, the driving current amounts can be controlled by adjusting the impurity concentrations of the first and second sources/drains **161** and **261**.

FIGS. **9A** and **9B** illustrate a circuit view and a layout view corresponding to a seventh embodiment of an integrated circuit device. FIG. **9C** illustrates only multiple fins and multiple gate electrodes from the layout view of FIG. **9B**. FIG. **9D** illustrates a cross-sectional view taken along the lines D-D and E-E of FIG. **9B**. The above-described embodiments of integrated circuit devices may be applied to all devices using fin-shaped transistors. The embodiments illustrated in FIGS. **9A** to **9D** may be applied to various devices, on example of which is an SRAM.

First, referring to FIG. **9A**, the integrated circuit device includes a pair of inverters **INV1** and **INV2** connected in parallel between a power supply node **Vcc** and a ground node **Vss**. The device also includes a first pass transistor **PS1** and a second pass transistor **PS2** connected to output nodes of the respective inverters **INV1** and **INV2**. The first pass transistor **PS1** and the second pass transistor **PS2** may be connected to a bit line **BL** and a complementary bit line **BL/**, respectively. Gates of the first pass transistor **PS1** and the second pass transistor **PS2** may be connected to a word line **WL**.

The first inverter **INV1** includes a first pull-up transistor **PU1** and a first pull-down transistor **PD1** connected in series to each other. The second inverter **INV2** includes a second pull-up transistor **PU2** and a second pull-down transistor **PD2** connected in series with each other. The first pull-up transistor **PU1** and the second pull-up transistor **PU2** may be PMOS transistors, and the first pull-down transistor **PD1** and the second pull-down transistor **PD2** may be NMOS transistors. In order to constitute a latch circuit, an input node of the first inverter **INV1** is connected to an output node of the second inverter **INV2**, and an input node of the second inverter **INV2** is connected to an output node of the first inverter **INV1**.

Referring to FIGS. **9B** to **9D**, a first fin **310**, a second fin **320**, a third fin **330**, and a fourth fin **340**, which are spaced apart from one another, may extend lengthwise in a predetermined direction (e.g., in an up-and-down direction of FIG. **9**). The second fin **320** and the third fin **330** may extend in smaller lengths than the first fin **310** and the fourth fin **340**.

A first gate electrode **351**, a second gate electrode **352**, a third gate electrode **353**, and a fourth gate electrode **354** are formed to extend in another direction (for example, in a left-and-right direction of FIG. **9**) to intersect the first fin **310** to the fourth fin **340**. In one embodiment, the first gate electrode **351** completely intersects the first fin **310** and the second fin **320**, while partially overlapping a terminal of the third fin **330**. The third gate electrode **353** may completely intersect the fourth fin **340** and the third fin **330**, while partially overlapping a terminal of the second fin **320**. The second gate electrode **352** and the fourth gate electrode **354** may be formed to intersect the first fin **310** and the fourth fin **340**, respectively.

As shown, the first pull-up transistor **PU1** is defined in a vicinity of an intersection of the first gate electrode **351** and the second fin **320**. The first pull-down transistor **PD1** is defined in vicinity of an intersection of the first gate electrode **351** and the first fin **310**. The first pass transistor **PS1** is defined in a vicinity of an intersection of the second gate electrode **352** and the first fin **310**. The second pull-up transistor **PU2** is defined in a vicinity of an intersection of the third gate electrode **353** and the third fin **330**. The second pull-down transistor **PD2** is defined in a vicinity of an intersection of the third gate electrode **353** and the fourth fin **340**. The second pass transistor **PS2** is defined in a vicinity of an intersection of the fourth gate electrode **354** and the fourth fin **340**.

Recesses may be formed at opposite sides of the respective intersections of the first to fourth gate electrodes **351-354**. The first to fourth fins **310**, **320**, **330** and **340**, and sources/drains may be formed in the recesses.

In addition, a plurality of contacts **350** may be formed. A shared contact **361** may concurrently connect the second fin **320**, a third gate line **353**, and an interconnection **371**. The shared contact **361** may also concurrently connect the third fin **330**, a first gate line **351**, and an interconnection **372**. For example, the first pull-up transistor **PU1**, the first pull-down transistor **PD1**, the first pass transistor **PS1**, the second pull-up transistor **PU2**, the second pull-down transistor **PD2**, and the second pass transistor **PS2** may be all implemented by fin-shaped transistors and may have the configuration, for example, as any of those shown in FIGS. **1** to **8**.

In an exemplary embodiment, the integrated circuit device may have a configuration shown in FIG. **9D**. The first pull-up transistor **PU1** may include a second fin **320**, a first gate electrode **351** intersecting the second fin **320**, a first recess **321a** formed in the second fin **320** at either side of the first gate electrode **351**, and a first source/drain **321** formed in the first recess **321a**. The first pull-down transistor **PD1** may include a first fin **310**, a first gate electrode **351** intersecting the first fin **310**, a second recess **311a** formed in the first fin **310** at either side of the first gate electrode **351**, and a second source/drain **311** formed in the second recess **311a**.

In such a case, a thickness of the first source/drain **321** of the first pull-up transistor **PU1** may be different from a thickness of the second source/drain **311** of the first pull-down transistor **PD1**. For example, in order to reduce current consumption, a current amount of the first pull-up transistor **PU1** may be reduced. Therefore, the thickness of the first source/drain **321** of the first pull-up transistor **PU1** may be smaller than that of the second source/drain **311** of the first pull-down transistor **PD1**.

The first pass transistor **PS1** may include a first fin **310**, a second gate electrode **352** intersecting the first fin **310**, a third recess formed in the first fin **310** at either side of the second gate electrode **352**, and a third source/drain formed

in the third recess. As shown, the second source/drain and the third source/drain may share a node. A thickness of the first source/drain **321** of the first pull-up transistor **PU1** and a thickness of the third source/drain of the first pass transistor **PS1** may be different from each other.

The recesses of the first pull-up transistor **PU1** and the second pull-up transistor **PU2** in the first region I and the recesses of the first pull-down transistor **PD1**, the second pull-down transistor **PD2**, the first pass transistor **PS1**, and the second pass transistor **PS2** in the second region II may be performed by separate and/or different processes. In such a manner, driving current amounts of the first pull-up transistor **PU1** (and/or the second pull-up transistor **PU2**) can be reduced relative to those of the other transistors **PD1**, **PD2**, **PS1**, and **PS**.

FIG. 10A illustrates a conceptual diagram of an integrated circuit device according to a first arrangement (8a-th) of an eighth embodiment. Referring to FIG. 10A, in the integrated circuit device according to the 8a-th embodiment, a fin-shaped transistor **411** may be disposed in a logic region **410** and a fin-shaped transistor **421** may be disposed in an SRAM region **420**.

Like in FIGS. 1 to 8, the fin-shaped transistor **411** includes a first fin, a first recess formed in the first fin, and a first source/drain formed in the first recess. The second fin-shaped transistor **421** includes a second fin, a second recess formed in the second fin, and a second source/drain formed in the second recess. A depth of the first recess and a depth of the second recess may be different. In one application, a thickness and/or depth of the first source/drain may be different from a thickness and/or depth of the second source/drain. Also, stress applied to a channel of the fin-shaped transistor **411** and stress applied to a channel of the fin-shaped transistor **421** may be adjusted to be different from each other.

In one application, the depth of the first recess may be greater than that of the second recess. The depths may be set this way because better performance (i.e., a higher speed) may be required by the fin-shaped transistor **411** formed in the logic region **410** than by the fin-shaped transistor **421** formed in the SRAM region **420**.

FIG. 10A illustrates an example of the logic region **410** and the SRAM region **420**. However, other embodiments may be applied to a region where a different type of memory from the logic region **410** is formed (e.g., DRAM, MRAM, RRAM, PRAM, etc.).

FIG. 10B illustrates a conceptual diagram of a second arrangement (8b-th) of the eighth embodiment of an integrated circuit device. Referring to FIG. 10B, in this arrangement, different fin-shaped transistors **412** and **422** may be disposed in the logic region **410**. That is, a thickness of the source/drain of the fin-shaped transistor **412** and a thickness of the source/drain of the fin-shaped transistor **422** may be different from each other. Alternatively, stress applied to a channel of the fin-shaped transistor **412** and stress applied to a channel of the fin-shaped transistor **422** may be adjusted to be different from each other.

FIG. 10C illustrates a conceptual diagram of a third arrangement (8c-th) of the eighth embodiment of an integrated circuit device. Referring to FIG. 10C, in this arrangement, a plurality of blocks (e.g., **BLK1**, **BLK2**, etc.) are defined in a substrate. Different fin-shaped transistors may be provided for the respective blocks **BLK1** and **BLK2**.

Also, as shown in FIG. 10C, one or more fins **F5** and **F6** may be provided in each of the blocks **BLK1** and **BLK2**. A thickness of the fin-shaped transistor disposed in the block **BLK1** and a thickness of the fin-shaped transistor disposed

in the block **BLK2** may be different from each other. Alternatively, stress applied to a channel of the fin-shaped transistor disposed in the block **BLK1** and stress applied to a channel of the fin-shaped transistor disposed in the block **BLK2** may be different from each other.

FIG. 11A illustrates a ninth embodiment of an integrated circuit device. In this embodiment, current amounts of fin-shaped transistors **107** and **107a** may be controlled by adjusting the number of fins **F11**, **F12**, **F21** and **F22**.

The fin-shaped transistor **107** may include a plurality of first fins **F11** and **F12** spaced apart from and parallel to each other. A first gate electrode **147** may be disposed to intersect the plurality of first fin **F1**. The fin-shaped transistor **107a** may include a plurality of second fins **F21** and **F22** spaced apart and parallel to each other. A second gate electrode **247** may be disposed to intersect the second fin **F2**.

A thickness of a source/drain of the fin-shaped transistor **107** and a thickness of a source/drain of the fin-shaped transistor **107a** may be made different from each other.

A current amount of the fin-shaped transistor **107** may be increased by increasing the number of fins **F11** and **F12** used by the fin-shaped transistor **107**. For example, consider the case where a current amount of a fin-shaped transistor using one fin is  $j$ , a current amount of a fin-shaped transistor using two fins **F11** and **F12** is equal to  $2j$ . Current amounts of the fin-shaped transistors **107a** and **107** may be adjusted to be different from each other by a predetermined amount, e.g.,  $\alpha$ . For example, the current amount of the fin-shaped transistor **107a** may be approximately  $2j+\alpha$  or  $2j-\alpha$ , and the current amount of the fin-shaped transistor **107** may be  $2j$ . According to the ninth embodiment, the fin-shaped transistors **107** and **107a** may have various types of current amounts.

FIG. 11B illustrates a tenth embodiment of an integrated circuit device. In this embodiment, current amounts of fin-shaped transistors **109**, **108**, **107**, and **101** may be controlled by adjusting the number of fins **F1a**, **F1b**, **F2a**, **F2b**, **F3a**, **F3b**, **F4a** and **F4b** used by the fin-shaped transistors **109**, **108**, **107**, and **101**. The fin-shaped transistors **109** and **109a** use four fins **F1a** and **F2a**, respectively. Assuming that a current amount of a fin-shaped transistor using one fin is  $j$ , a current amount of the fin-shaped transistor **109** using four fins **F1a** becomes  $4j$ . In addition, a current amount of the fin-shaped transistor **109a** may be approximately  $4j+\alpha$  or  $4j-\alpha$ .

The fin-shaped transistors **108** and **108a** use three fins **F1b** and **F2b**, respectively. A current amount of the fin-shaped transistor **108** using three fins **F1b** becomes  $3j$ . In addition, a current amount of the fin-shaped transistor **108a** may be approximately  $3j+\alpha$  or  $3j-\alpha$ .

The fin-shaped transistors **107** and **107a** uses two fins **F1c** and **F2c**, respectively. A current amount of the fin-shaped transistor **107** using two fins **F2b** becomes  $2j$ . In addition, a current amount of the fin-shaped transistor **107a** may be approximately  $2j+\alpha$  or  $2j-\alpha$ .

The fin-shaped transistors **101** and **101a** use one fin **F1d** and **F2d**, respectively. A current amount of the fin-shaped transistor **101** using one fin **F1d** becomes  $j$ . In addition, a current amount of the fin-shaped transistor **101a** may be approximately  $j+\alpha$  or  $j-\alpha$ . Therefore, according to the tenth embodiment, the fin-shaped transistors **109**, **109a**, **108**, **108a**, **107**, **107a**, **101** and **101a** have different current amounts.

FIG. 12 illustrates an eleventh embodiment of an integrated circuit device which includes a first nanowire-shaped transistor **1101** and a second nanowire-shaped transistor **1201**. A nanowire-shaped transistor may also be referred to

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as a gate-all-around device. The first and second nanowire-shaped transistors **1101**, **1201** use nanowires **n1** and **n2**, instead of fins (e.g., **F1** and **F2** of FIGS. **1** to **3**).

The first nanowire-shaped transistor **1101** may include a first nanowire **n1**, a first gate electrode **147** formed on the first nanowire **n1** to intersect the first nanowire **n1**, and a first source/drain **161** formed in the first nanowire **n1** at either side of the first gate electrode **147**.

The second nanowire-shaped transistor **1201** may include a second nanowire **n2**, a second gate electrode **247** formed on the second nanowire **n2** to intersect the second nanowire **n2**, and a second source/drain **261** formed in the second nanowire **n2** at either side of the second gate electrode **247**.

In the illustrated embodiment, cross-sectional shapes of the first and second nanowires **n1** and **n2** are circular. In other embodiments, the cross-sectional shapes of the first and second nanowires **n1** and **n2** may be oval, rectangular, square, or another shape. In one implementation, a thickness of a first source/drain **161** of the first nanowire-shaped transistor **1101** and a thickness of a second source/drain **261** of the second nanowire-shaped transistor **1201** may be different from each other.

FIG. **13A** illustrates a conceptual diagram of a first arrangement (**12a-th**) of a twelfth embodiment of an integrated circuit device. In this arrangement, a first nanowire-shaped transistor **1102** and a second nanowire-shaped transistor **1202** include multiple nanowires **n11**, **n12**, **n21** and **n22** stacked vertically one on another. In the illustrated embodiment, two nanowires are stacked. In other embodiments, three or more nanowires may be stacked one on another.

In detail, the first nanowire-shaped transistor **1102** includes multiple first nanowires **n11** and **n12** stacked vertically. A first source/drain **161** is electrically connected to **n** first nanowires among the multiple first nanowires **n11** and **n12**, where **n** is a natural number, e.g., **1**. That is to say, only one first nanowire **n12** may be used in this particular arrangement.

The second nanowire-shaped transistor **1202** includes multiple second nanowires **n21** and **n22** stacked vertically. A second source/drain **261** is electrically connected to **m** second nanowires among the multiple second nanowires **n21** and **n22**, where **m** is a natural number different from **n**, e.g., **2**. That is to say, two second nanowires **n21** and **n22** may be used in this particular arrangement.

The driving current amounts can be controlled by varying the number of nanowires **n11**, **n12**, **n21**, and **n22** used. For example, a current amount of the first nanowire-shaped transistor **1102** using one nanowire may be **j**, and a current amount of the second nanowire-shaped transistor **1202** using two nanowires may be **2j**.

FIG. **13B** illustrates a second arrangement (**12b-th**) of the twelfth embodiment of an integrated circuit device. Referring to FIG. **13B**, a first nanowire-shaped transistor **1103** and a second nanowire-shaped transistor **1203** include three or more nanowires **n11** to **n14** and **n21** to **n24**, respectively. The number of first nanowires **n11** to **n14** in the first nanowire-shaped transistor **1103** and the number of second nanowires **n21** to **n24** in the second nanowire-shaped transistor **1203** may be the same.

For example, the first nanowire-shaped transistor **1103** may include multiple first nanowires **n11** to **n14** stacked vertically. A first source/drain **161** may be electrically connected to **n** first nanowires among the multiple first nanowires **n11** to **n14**, where **n** is a natural number, e.g., **2**. Thus, only two first nanowires **n13** and **n14** may be used. The **n** first nanowires **n11** to **n14** may be sequentially arranged,

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with the topmost first nanowire corresponding to **n14**. In FIG. **13B**, two first nanowires are used from the topmost first nanowire, that is, **n14** and **n13**.

The second nanowire-shaped transistor **1203** includes multiple second nanowires **n21** to **n24** stacked vertically. A second source/drain **261** is electrically connected to **m** second nanowires among the multiple second nanowires **n21** to **n24**, where **m** is a natural number, e.g., **3**. That is to say, three second nanowires **n22**, **n23** and **n24** may be used. The **m** second nanowires **n21** to **n24** may be sequentially arranged, with the topmost second nanowire corresponding to **n24**. In FIG. **13B**, three second nanowires **n24**, **n23** and **n22** are used.

The number of first nanowires **n11** to **n14** in the first nanowire-shaped transistor **1103** and the number of second nanowires **n21** to **n24** in the second nanowire-shaped transistor **1203** may be the same. In FIG. **13B**, four of the first nanowires **n11** to **n14** and the second nanowires **n21** to **n24** are stacked.

The driving current amounts may be controlled by varying the number of nanowires **n11** to **n14** and **n21** to **n24** used. Assuming that a current amount of the first nanowire-shaped transistor **1102** using two nanowires is **2j**, a current amount of the second nanowire-shaped transistor **1202** using three nanowires is **3j**.

In the integrated circuit devices according to the first and second twelfth (**12a-th** and **12b-th**) embodiments, the numbers of exposed nanowires may be made to be different from each other by varying depths of recesses in forming the first source/drain **161** and the second source/drain **261**, thereby controlling the number of nanowires used.

FIGS. **14** to **26** illustrate one embodiment of a method of making an integrated circuit device. In FIGS. **14** to **20**, only the first fin-shaped transistor (**101** of FIG. **1**) is exemplified because the operations for forming the first fin-shaped transistor **101** and the second fin-shaped transistor (**201** of FIG. **1**) may be substantially the same. In FIGS. **21** to **26**, the first fin-shaped transistor **101** and the second fin-shaped transistor **201** are separately illustrated. FIGS. **22** and **25** are cross-sectional views taken along the line A-A of FIGS. **21** and **24**, respectively. FIGS. **23** and **26** illustrate cross-sectional views taken along the lines B-B and C-C of FIG. **24**, respectively.

Referring to FIG. **14**, a first fin **F1** is formed in a first region **I**. To form the first fin **F1**, a mask pattern **2103** is formed on a substrate **100**. An etching process is then performed to form the first fin **F1**. The first fin **F1** may extend in a second direction **Y1**. The trench **121** is formed around the first fin **F1**. The mask pattern **2103** may be made of at least one material selected from the group consisting of silicon oxide, silicon nitride, and silicon oxynitride.

Referring to FIG. **15**, an isolation film **110** filling the trench **121** is formed. The isolation film **110** may be made of at least one material selected from the group consisting of silicon oxide, silicon nitride, and silicon oxynitride.

Referring to FIG. **16**, a top portion of the isolation film **110** is recessed to expose a top portion of the first fin **F1**. The recessing may include a selective etching process. The mask pattern **2103** may be removed before forming the isolation film **110** or after performing the recess process.

Meanwhile, a portion of the first fin **F1** protruding above the isolation film **110** may be formed by an epitaxial process. More specifically, after forming the isolation film **110**, a portion of the first fin **F1** may be formed by an epitaxial process using a top surface of the first fin **F1** exposed by the isolation film **110** and without a recess process as a seed.

In addition, doping for adjusting a threshold voltage may be performed on the first fin F1. In a case where the fin-shaped transistor **101** is an NMOS transistor, the impurity doped may be boron (B). In a case where the fin-shaped transistor **101** is a PMOS transistor, the impurity doped may be phosphorus (P) or arsenic (As).

Referring to FIG. 17, an etching process is performed using the mask pattern **2104**, to thereby form a dummy gate insulation layer **141** and a first dummy gate electrode **143** extending in a first direction X1 and intersecting or overlapping the first fin F1. For example, the dummy gate insulation layer **141** may include silicon oxide, and the first dummy gate electrode **143** may include polysilicon.

Referring to FIG. 18, a first spacer **151** is formed on sidewalls of the first dummy gate electrode **143** and sidewalls of the first fin F1. For example, an insulation layer is formed on the resultant product having the first dummy gate electrode **143** formed thereon. An etch-back process may then be performed, to thereby form the first spacer **151**. The first spacer **151** may expose the top surface of the mask pattern **2104** and the top surface of the first fin F1. The first spacer **151** may include silicon nitride or silicon oxynitride.

Referring to FIG. 19, an interlayer insulation layer **155** is formed on the resultant product having the first spacer **151** formed thereon. The interlayer insulation layer **155** may include silicon oxide. The interlayer insulation layer **155** may be planarized until the top surface of the first dummy gate electrode **143** is exposed. As the result, the mask pattern **2104** may be removed, and the top surface of the first dummy gate electrode **143** may be exposed.

Referring to FIG. 20, the dummy gate insulation layer **141** and the first dummy gate electrode **143** are removed. As the dummy gate insulation layer **141** and the first dummy gate electrode **143** are removed, a trench **123** exposing the isolation film **110** is formed.

Referring to FIGS. 21 to 23, the first gate insulation layer **145** and the first gate electrode **147** are formed in the trench **123**. The first gate insulation layer **145** may include a high-k material having a higher dielectric constant than silicon oxide. For example, the first gate insulation layer **145** may include HfO<sub>2</sub>, ZrO<sub>2</sub> or Ta<sub>2</sub>O<sub>5</sub>. The first gate insulation layer **145** may be substantially conformally formed along sidewalls and bottom surface of the trench **123**.

The first gate electrode **147** may include metal layers MG1 and MG2. As shown, the first gate electrode **147** may include two or more metal layers MG1 and MG2 stacked. The first metal layer MG1 may function to adjust a work function, and the second metal layer MG2 may function to fill a space formed by the first metal layer MG1. For example, the first metal layer MG1 may include at least one of TiN, TaN, TiC, or TaC. The second metal layer MG2 may include W or Al. Alternatively, the first gate electrode **147** may include a material other than a metal, such as Si or SiGe.

In the same manner as described above, a second gate insulation layer **245** and a second gate electrode **247** are formed in a second region II. The second gate electrode **247** may include metal layers MG3 and MG4.

Referring to FIGS. 24 to 26, in the first region I, a first recess **125** is formed in a first fin F1 at either side of the first gate electrode **147**. In the second region II, a second recess **225** is formed in a second fin F2 at either side of the second gate electrode **247**. For the recesses, a depth of the first recess **125** of the first fin-shaped transistor **101** may be different from a depth of the second recess **225** of the second fin-shaped transistor **201**.

The processes of forming the first recess **125** and forming of the second recess **225** may be separately performed. For example, etching may be performed using a first mask which exposes the first region I, but which does not expose the second region II. Thereafter, etching may be performed using a second mask which exposes the second region II, but which does not expose the first region I. The etching may be, for example, dry etching or a combination of wet etching and dry etching.

Referring again to FIGS. 1 to 3, the first source/drain **161** is formed in the first recess **125** and the second source/drain **261** is formed in the second recess **225**. For example, the first source/drain **161** may be an elevated source/drain. In addition, the first source/drain **161** and second source/drain **261** may be performed by an epitaxial process. In addition, materials of the first source/drain **161** and the second source/drain **261** may vary according to whether the first fin-shaped transistor **101** and the second fin-shaped transistor **201** are PMOS transistors or NMOS transistors. Impurities may be in-situ doped during the epitaxial process. Also, the first recess **125** and the second recess **225** may be filled with a metal, instead of a semiconductor material.

FIGS. 27 to 29 describe an embodiment of a method for forming fins that can be used in the fabrication of one or more of the aforementioned embodiments of the integrated circuit devices. The method described in FIGS. 27 to 29 may include a method for forming multiple fins shown in FIG. 11A, for example, a sidewall image transfer (SIT) process. FIGS. 27 to 29 illustrate a method of two fins by way of example, this embodiment may be analogously applied to forming a different numbers of fins in other embodiments.

Referring to FIG. 27, a sacrificial pattern **501** is formed on a substrate **100**. Next, a mask layer **505** is formed on the substrate **100** having the sacrificial pattern **501** formed thereon. The mask layer **505** may be conformally formed along the top surface of the substrate **100** having the sacrificial pattern **501** thereon. The sacrificial pattern **501** and the mask layer **505** may be made of materials having etching selectivity to each other. For example, the mask layer **505** may include at least one selected from the group consisting of silicon oxide, silicon nitride, silicon oxynitride, photo resist, spin on glass (SOG), and spin on hard mask (SOH). The sacrificial pattern **501** may be made of a material such as any of those listed above, which is different from the material forming the mask layer **505**.

In addition, the sacrificial pattern **501** and the mask layer **505** may be formed by a method selected from the group consisting of a physical vapor deposition process (PVD), a chemical vapor deposition process (CVD), an atomic layer deposition (ALD) and spin coating.

Referring to FIG. 28, spacer-shaped mask patterns **506** are formed on sidewalls of the sacrificial pattern **501** using an etch-back process. Next, the sacrificial pattern **501** is removed. The mask patterns **506** have substantially the same width. A trench **511** may be formed between the mask patterns **506**.

Referring to FIG. 29, the substrate **100** is etched using the mask patterns **506** as etch masks substrate **100**. As the result, fins F11 and F12 having a constant width may be formed. A trench **512** may be formed between the fins F11 and F12 adjacent to each other by an etching process. With the etching process, top portions of the mask patterns **506** are etched together, to thereby provide mask patterns **506** having rounded top portions. Then, the mask patterns **506** are removed, thereby completing fins F11 and F12 which are spaced apart from each other and have a constant width.

FIG. 30 illustrates an embodiment of an electronic system including an integrated circuit device corresponding to any of the aforementioned embodiments. Referring to FIG. 30, the electronic system 1100 may include a controller 1110, an input/output device (I/O) 1120, a memory device 1130, an interface 1140, and a bus 1150. The controller 1110, the I/O 1120, the memory device 1130, and/or the interface 1140 may be connected to each other through the bus 1150. The bus 1150 corresponds to a path through which data moves.

The controller 1110 may include at least one of a micro-processor, a digital signal processor, a microcontroller, and logic elements capable of functions similar to those of these elements. The I/O 1120 may include a keypad, a keyboard, a display device, and so on. The memory device 1130 may store data and/or codes. The interface 1140 may perform functions of transmitting data to a communication network or receiving data from the communication network. The interface 1140 may be wired or wireless. For example, the interface 1140 may include an antenna or a wired/wireless transceiver, and so on.

The electronic system 1100 may further include high-speed DRAM and/or SRAM as the operating memory for improving the operation of the controller 1110. Fin-type FETs according to the embodiments described herein may be incorporated into the memory device 1130 or provided as part of the controller 1110 or the I/O 1120.

The electronic system 1100 may be applied to a personal digital assistant (PDA), a portable computer, a web tablet, a wireless phone, a mobile phone, a digital music player, a memory card, or any type of electronic device capable of transmitting and/or receiving information in a wireless environment.

FIGS. 31 and 32 illustrate embodiments of a semiconductor system which may include any of the aforementioned embodiments of the integrated circuit device. FIG. 31 illustrates an example in which the integrated circuit device is applied to a tablet PC. FIG. 32 illustrates an example in which the integrated circuit device is applied to a notebook computer. At least one of the integrated circuit devices may be used for a tablet PC, a notebook computer, smart phone, media player, pad- or pod-type device, or another type of communication device and/or information processing system.

In accordance with one or more embodiments, an integrated circuit device is provided which can control current amount by adjusting a thickness of source/drain and/or other device parameters. Also, embodiments of a method for making integrated circuit devices are provided which can control a current amount by adjusting a thickness of source/drain and/or other device parameters.

Example embodiments have been disclosed herein, and although specific terms are employed, they are used and are to be interpreted in a generic and descriptive sense only and not for purpose of limitation. In some instances, as would be apparent to one of ordinary skill in the art as of the filing of the present application, features, characteristics, and/or elements described in connection with a particular embodiment may be used singly or in combination with features, characteristics, and/or elements described in connection with other embodiments unless otherwise specifically indicated. Accordingly, it will be understood by those of skill in the art that various changes in form and details may be made without departing from the spirit and scope of the present invention as set forth in the following claims.

What is claimed is:

[1. A fabricating method of an integrated circuit device, the method comprising:

providing a substrate having a first region and a second region defined therein;

forming a first fin in the first region and forming a second fin in the second region;

forming a first gate electrode intersecting the first fin in the first region and forming a second gate electrode intersecting the second fin in the second region;

forming a first recess in the first fin at either side of the first gate electrode in the first region and forming a second recess in the second fin at either side of the second gate electrode in the second region;

forming a first source/drain in the first recess; and forming a second source/drain in the second recess, wherein a depth of the first recess is different from a depth of the second recess, and wherein

an impurity concentration of the first source/drain is different from an impurity concentration of the second source/drain.]

[2. The method as claimed in claim 1, wherein the first source/drain has a first thickness in the first recess and the second source/drain has a second thickness in the second recess.]

[3. The method as claimed in claim 2, wherein the first thickness of the first source/drain is different from the second thickness of the second source/drain.]

[4. The method as claimed in claim 1, wherein the forming the first source/drain and the second source/drain comprises using an epitaxial process, and impurities of the first source/drain and the second source/drain is in-situ doped during the epitaxial process.]

[5. The method as claimed in claim 1, wherein the forming the first fin and the second fin comprises:

forming a mask pattern on the substrate, and etching the substrate using the mask pattern as an etch mask.]

6. An integrated circuit device comprising:  
a substrate including a first region and a second region;  
a first nanowire shaped transistor disposed on the first region of the substrate, and including a first source/drain; and

a second nanowire shaped transistor disposed on the second region of the substrate, and including a second source/drain, wherein:

the first source/drain has a first thickness, and the second source/drain has a second thickness that is different from the first thickness, lower surfaces of the first source/drain and the second source/drain being at different heights relative to a bottom of the substrate.

7. The integrated circuit device of claim 6, wherein the first region is a logic region, and the second region is an SRAM region.

8. The integrated circuit device of claim 6, wherein each of the first region and the second region is a logic region.

9. The integrated circuit device of claim 6, wherein the first nanowire shaped transistor is a pull-up transistor, and the second nanowire shaped transistor is a pull-down transistor or a pass transistor.

10. The integrated circuit device of claim 6, wherein the first nanowire shaped transistor includes  $K$  first nanowires that are stacked vertically one on another,  $K$  being an integer greater than one, and

the second nanowire shaped transistor includes  $L$  second nanowires that are stacked vertically one on another,  $L$  being an integer greater than one.

11. The integrated circuit device of claim 10, wherein  $K$  is equal to  $L$ .



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12. The integrated circuit device of claim 11, wherein the first source/drain is connected to  $M$  nanowires among the  $K$  first nanowires,  $M$  being a positive integer, and

the second source/drain is connected to  $N$  nanowires among the  $L$  second nanowires,  $N$  being a positive integer.

13. The integrated circuit device of claim 12, wherein  $M$  is different from  $N$ .

14. The integrated circuit device of claim 10, wherein a cross-sectional shape of the  $K$  first nanowires and the  $L$  second nanowires is oval or rectangular.

15. The integrated circuit device of claim 6, wherein the first nanowire shaped transistor is a PMOS transistor.

16. The integrated circuit device of claim 6, wherein each of the first nanowire shaped transistor and the second nanowire shaped transistor is a PMOS transistor.

17. The integrated circuit device of claim 6, wherein each of the first nanowire shaped transistor and the second nanowire shaped transistor is an NMOS transistor.

18. The integrated circuit device of claim 6, wherein each of the first source/drain and the second source/drain includes SiGe, and

each of a first channel of the first nanowire shaped transistor and a second channel of the second nanowire shaped transistor includes Si.

19. The integrated circuit device of claim 6, wherein each of the first source/drain and the second source/drain includes SiC, and

each of a first channel of the first nanowire shaped transistor and a second channel of the second nanowire shaped transistor includes Si.

20. The integrated circuit device of claim 6, wherein each of the first source/drain and the second source/drain includes SiC or Si.

21. The integrated circuit device of claim 6, wherein each of the first source/drain and the second source/drain has a first lattice constant.

22. The integrated circuit device of claim 21, wherein each of a first channel of the first nanowire shaped transistor and a second channel of the second nanowire shaped transistor has a second lattice constant that is different from the first lattice constant.

23. The integrated circuit device of claim 6, further comprising:

a first gate electrode disposed on the first region of the substrate; and

a second gate electrode disposed on the second region of the substrate,

wherein the first gate electrode includes a first metal layer and a second metal layer disposed on the first metal layer, and

the second gate electrode includes a third metal layer and a fourth metal layer disposed on the third metal layer.

24. The integrated circuit device of claim 23, wherein the first metal layer includes TiN, TaN, TiC or TaC, and the second metal layer includes W or Al.

25. The integrated circuit device of claim 23, wherein each of the first metal layer and the third metal layer is U-shaped.

26. The integrated circuit device of claim 23, wherein each of the first gate electrode and the second gate electrode is U-shaped.

27. The integrated circuit device of claim 6, further comprising:

a first gate insulation layer disposed on the first region of the substrate; and

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a second gate insulation layer disposed on the second region of the substrate, wherein the first gate insulation layer includes a high- $k$  material having a higher dielectric constant than silicon oxide.

28. The integrated circuit device of claim 27, wherein the first gate insulation layer includes HfO<sub>2</sub>, ZrO<sub>2</sub> or Ta<sub>2</sub>O<sub>5</sub>.

29. An integrated circuit device comprising:

a substrate including a first region and a second region; a first transistor disposed on the first region of the substrate, and including a first source/drain and  $K$  nanowires,  $K$  being an integer greater than one; and a second transistor disposed on the second region of the substrate, and including a second source/drain and  $K$  nanowires,

wherein the first source/drain has a first thickness, the second source/drain has a second thickness that is different from the first thickness,

the first source/drain is directly contacting and electrically connected to  $M$  nanowires among the  $K$  nanowires of the first transistor,  $M$  being a positive integer, and

the second source/drain is directly contacting and electrically connected to  $N$  nanowires among the  $K$  nanowires of the second transistor,  $N$  being a positive integer different from  $M$ , a difference between  $M$  and  $N$  corresponding to a difference in thickness between the first source/drain and the second source/drain.

30. The integrated circuit device of claim 29, wherein the first region is a logic region, and the second region is an SRAM region.

31. The integrated circuit device of claim 29, wherein each of the first region and the second region is a logic region.

32. The integrated circuit device of claim 29, wherein the first transistor is a PMOS transistor.

33. The integrated circuit device of claim 29, wherein each of the first transistor and the second transistor is a PMOS transistor.

34. The integrated circuit device of claim 29, wherein each of the first transistor and the second transistor is an NMOS transistor.

35. An integrated circuit device comprising:

a substrate including a first region and a second region; a first fin-shaped transistor disposed on the first region of the substrate, and including a first source/drain and a first channel; and

a second fin-shaped transistor disposed on the second region of the substrate, and including a second source/drain and a second channel,

wherein the first source/drain has a first thickness, the second source/drain has a second thickness that is different from the first thickness,

a lower surface of the first source/drain is disposed higher than an upper surface of the substrate,

a lower surface of the second source/drain is disposed higher than the upper surface of the substrate, the lower surfaces of the first source/drain and the second source/drain being at different heights relative to a bottom of the substrate, and

each of the first channel and the second channel includes Si.

36. The integrated circuit device of claim 35, wherein the first region is a logic region, and the second region is an SRAM region.

37. The integrated circuit device of claim 35, wherein the first fin-shaped transistor is a pull-up transistor, and

*the second fin-shaped transistor is a pull-down transistor or a pass transistor.*

*38. The integrated circuit device of claim 35 wherein the first fin-shaped transistor is a PMOS transistor.*

*39. The integrated circuit device of claim 35, wherein 5 each of the first fin-shaped transistor and the second fin-shaped transistor is a PMOS transistor.*

*40. The integrated circuit device of claim 35, wherein a first stress applied by the first source/drain to a first channel of the first fin-shaped transistor is different from a second 10 stress applied by the second source/drain to a second channel of the second fin-shaped transistor.*

*41. The integrated circuit device of claim 40, wherein the first channel and the second channel have a same second lattice constant that is different from a first lattice constant. 15*

*42. The integrated circuit device of claim 35, wherein the first source/drain includes a compressive stress material.*

*43. The integrated circuit device of claim 35, wherein the substrate is a silicon on insulator (SOI) substrate.*

*44. The integrated circuit device of claim 35, wherein the 20 first fin-shaped transistor includes a first fin having a width of 20 nm or less.*

\* \* \* \* \*